Summaries of life the science of biology 10th edition 2012

www.Archive.org/details/lifethescienceofbiology10thedition2012davidsadavadavidm.hillish.craigheller mayr.berenbaum120mb

Summaries of all the 59 chapters

PART ONE, THE SCIENCE OF LIFE AND ITS CHEMICAL BASIS

CHAPTER 1 Studying Life

1.1 What Is Biology? • Biology is the scientific study of living organisms, including their characteristics, functions, and interactions. • All living organisms are related to one another through common descent. Shared features of all living organisms, such as specific chemical building blocks, a nearly universal genetic code, and sequence similarities across fundamental genes, support the common ancestry of life. • Cells evolved early in the history of life. Cellular specialization allowed multicellular organisms to increase in size and diversity. Review Figure 1.2 • The instructions for a cell are contained in its genome, which consists of DNA molecules made up of sequences of nucleotides. Specific segments of DNA called genes contain the information the cell uses to make proteins. Review Figure 1.5 • Photosynthesis provided a means of capturing energy directly from sunlight and over time changed Earth's atmosphere. • Evolution—change in the genetic makeup of biological populations through time—is a fundamental principle of life. Populations evolve through several different processes, including natural selection, which is responsible for the diversity of adaptations found in living organisms. • Biologists use fossils, anatomical similarities and differences, and molecular comparisons of genomes to reconstruct the history of life. Three domains—Bacteria, Archea, and Eukarya—represent the major divisions, which were established very early in life's history. Review Figure 1.7, ACTIVITY 1.1 • Life can be studied at different levels of organization within a biological hierarchy. The specialized cells of multicellular organisms are organized into tissues, organs, and organ systems. Individual organisms form populations and interact with other organisms of their own and other species. The populations that live and interact in a defined area form a community, and communities together with their abiotic (nonliving) environment constitute an ecosystem. Review Figure 1.9, ACTIVITY 1.2 • Living organisms, whether unicellular or multicellular, must regulate their internal environment to maintain homeostasis, the range of physical conditions necessary for their survival and function.

1.2 How Do Biologists Investigate Life? • Scientific methods combine observation, gathering information (data), experimentation, and logic to study the natural world. Many scientific investigations involve five steps: making observations, asking questions, forming hypotheses, making predictions, and testing those predictions. Review Figure 1.10 • Hypotheses are tentative answers to questions. Predictions made on the basis of a hypothesis are tested with additional observations and two kinds of experiments, comparative and controlled experiments. Review Figures 1.11, 1.12, ANIMATED TUTORIAL 1.1 • Quantifiable data are critical in evaluating hypotheses. Statistical methods are applied to quantitative data to establish whether or not the differences observed could be the result of chance.

These methods start with the null hypothesis that there are no differences. See Appendix B • Biological knowledge obtained from a model system may be generalized to other species.

1.3 Why Does Biology Matter? • Application of biological knowledge is responsible for vastly increased agricultural production. • Understanding and treatment of human disease requires an integration of a wide range of biological principles, from molecular biology through cell biology, physiology, evolution, and ecology. • Biologists are often called on to advise government agencies on the solution of important problems that have a biological component. • Biology is increasing important for understanding how organisms interact in a rapidly changing world. • Biology helps us understand and appreciate the diverse living world.

CHAPTER 2 Small Molecules and the Chemistry of Life

2.1 How Does Atomic Structure Explain the Properties of Matter? • Matter is composed of atoms. Each atom consists of a positively charged nucleus made up of protons and neutrons, surrounded by electrons bearing negative charges. Review Figure 2.1 • The number of protons in the nucleus defines an element. There are many elements in the universe, but only a few of them make up the bulk of living organisms: C, H, O, P, N, and S. Review Figure 2.2 • Isotopes of an element differ in their numbers of neutrons. Radioisotopes are radioactive, emitting radiation as they break down. • Electrons are distributed in electron shells, which are volumes of space defined by specific numbers of orbitals. Each orbital contains a maximum of two electrons. Review Figures 2.4, 2.5, ACTIVITY 2.1 • In losing, gaining, or sharing electrons to become more stable, an atom can combine with other atoms to form a molecule.

2.2 How Do Atoms Bond to Form Molecules? See ANIMATED TUTORIAL 2.1 • A chemical bond is an attractive force that links two atoms together in a molecule. Review Table 2.1 • A compound is a substance made up of molecules with two or more different atoms bonded together in a fixed ratio, such as water (H2 O). • Covalent bonds are strong bonds formed when two atoms share one or more pairs of electrons. Review Figure 2.6 • When two atoms of unequal electronegativity bond with each other, a polar covalent bond is formed. The two ends, or poles, of the bond have partial charges (δ+ or δ–). Review Figure 2.8 • An ion is an electrically charged body that forms when an atom gains or loses one or more electrons in order to form a more stable electron configuration. Anions and cations are negatively and positively charged ions, respectively. Different charges attract, and like charges repel each other. • Ionic attractions occur between oppositely charged ions. Ionic attractions are strong in solids (salts) but weaken when the ions are separated from one another in solution. Review Figure 2.9 • A hydrogen bond is a weak electrical attraction that forms between a δ+ hydrogen atom in one molecule and a δ– atom in another molecule (or in another part of the same, large molecule). Hydrogen bonds are abundant in water. Review Figure 2.11 • Nonpolar molecules interact very little with polar molecules, including water. Nonpolar molecules are attracted to one another by very weak bonds called van der Waals forces.

2.3 How Do Atoms Change Partners in Chemical Reactions? • In chemical reactions, atoms combine or change their bonding partners. Reactants are converted into products. • Some chemical reactions release energy as one of their products; other reactions can occur only if energy is provided to the reactants. • Neither matter nor energy is created or destroyed in a chemical reaction, but both change form. Review Figure 2.13 • Some chemical reactions, especially in biology, are reversible. That is, the

products formed may be converted back to the reactants. • In organisms, chemical reactions take place in multiple steps so that released energy can be harvested for cellular activities.

2.4 What Makes Water So Important for Life? • Water's molecular structure and its capacity to form hydrogen bonds give it unique properties that are significant for life. Review Figure 2.14 • The high specific heat of water means that water gains or loses a great deal of heat when it changes state. Water's high heat of vaporization ensures effective cooling when water evaporates. • The cohesion of water molecules refers to their capacity to resist coming apart from one another. Hydrogen bonding between the water molecules plays an essential role in this property. • A solution is produced when a solid substance (the solute) dissolves in a liquid (the solvent). Water is the critically important solvent for life.

CHAPTER 3 Proteins, Carbohydrates, and Lipids

3.1 What Kinds of Molecules Characterize Living Things? See ANIMATED TUTORIAL 3.1 • Macromolecules are polymers constructed by the formation of covalent bonds between smaller molecules called monomers. Macromolecules in living organisms include polysaccharides, proteins, and nucleic acids. Large lipid structures may also be considered macromolecules. • Functional groups are small groups of atoms that are consistently found together in a variety of different macromolecules. Functional groups have particular chemical properties that they confer on any larger molecule of which they are a part. Review Figure 3.1, ACTIVITY 3.1 • Structural, cis-trans, and optical isomers have the same kinds and numbers of atoms but differ in their structures and properties. Review Figure 3.2 • The many functions of macromolecules are directly related to their three-dimensional shapes, which in turn result from the sequences and chemical properties of their monomers. • Monomers are joined by condensation reactions, which release a molecule of water for each bond formed. Hydrolysis reactions use water to break polymers into monomers. Review Figure 3.4

3.2 What Are the Chemical Structures and Functions of Proteins? • The functions of proteins include support, protection, catalysis, transport, defense, regulation, and movement. Review Table 3.1 • Proteins consist of one or more polypeptide chains, which are polymers of amino acids. Four atoms or groups are attached to a central carbon atom: a hydrogen atom, an amino group, a carboxyl group, and a variable R group. The particular properties of each amino acid depend on its side chain, or R group, which may be charged, polar, or hydrophobic. Review Table 3.2, ACTIVITY 3.2 • Peptide linkages, also called peptide bonds, covalently link amino acids into polypeptide chains. These bonds form by condensation reactions between the carboxyl and amino groups. Review Figure 3.6 • The primary structure of a protein is the sequence of amino acids in the chain. This chain is folded into a secondary structure, which in different parts of the protein may form an a (alpha) helix or a b pleated sheet. Review Figure 3.7A–C • Disulfide bridges and noncovalent interactions between amino acids cause polypeptide chains to fold into three-dimensional tertiary structures. Weak, noncovalent interactions allow multiple poly-peptide chains to form quaternary structures. Review Figure 3.7D, 3.7E

Heat, alterations in pH, or certain chemicals can all result in a protein becoming denatured. This involves the loss of tertiary and/or secondary structure as well as biological function. Review Figure 3.10 • The specific shape and structure of a protein allows it to bind noncovalently to other molecules. In addition, amino acids may be modified by the covalent bonding of chemical groups to their side chains. Such

binding may result in the protein changing its shape. Review Figures 3.12, 3.13 • Chaperone proteins enhance correct protein folding and prevent inappropriate binding to other molecules. Review Figure 3.14

3.3 What Are the Chemical Structures and Functions of Carbohydrates? • Carbohydrates contain carbon bonded to hydrogen and oxygen atoms and have the general formula $C_mH_{2n}O_n$. • Monosaccharides are the monomers that make up carbohydrates. Hexoses such as glucose are six-carbon monosaccharides; pentoses have five carbons. Review Figure 3.16, ACTIVITY 3.3 • Glycosidic linkages, which have either an α or a β orientation in space, are covalent bonds between monosaccharides. Two linked monosaccharides are called disaccharides; larger units are oligosaccharides and polysaccharides. Review Figure 3.17 • Starch is a polymer of glucose that stores energy in plants, and glycogen is an analogous polymer in animals. They can be easily broken down to release stored energy. Review Figure 3.18 • Cellulose is a very stable glucose polymer and is the principal structural component of plant cell walls.

3.4 What Are the Chemical Structures and Functions of Lipids? • Lipids are hydrocarbons that are insoluble in water because of their many nonpolar covalent bonds. They play roles in energy storage, membrane structure, light harvesting, regulation, and protection. • Fats and oils are triglycerides. A triglyceride is composed of three fatty acids covalently bonded to a molecule of glycerol by ester linkages. Review Figure 3.20 • A saturated fatty acid has a hydrocarbon chain with no double bonds. These molecules can pack together tightly. The hydrocarbon chain of an unsaturated fatty acid has one or more double bonds that bend the chain, preventing close packing. Review Figure 3.21 • A phospholipid has a hydrophobic hydrocarbon “tail” and a hydrophilic phosphate “head”; that is, it is amphipathic. In water, the interactions of the tails and heads of phospholipids generate a phospholipid bilayer. The heads are directed outward, where they interact with the surrounding water. The tails are packed together in the interior of the bilayer, away from water. Review Figure 3.22 • Other lipids include vitamins A, D, E, and K, steroids, and plant pigments such as carotenoids.

CHAPTER 4 Nucleic Acids and the Origin of Life

4.1 What Are the Chemical Structures and Functions of Nucleic Acids? • The unique functions of the nucleic acids—DNA and RNA—are information storage and transfer. DNA is the hereditary material that passes genetic information from one generation to the next, and RNA uses that information to specify the structures of proteins. • Nucleic acids are polymers of nucleotides. A nucleotide consists of a phosphate group, a pentose sugar (ribose in RNA and deoxyribose in DNA), and a nitrogen-containing base. Review Figure 4.1 • In DNA, the nucleotide bases are adenine (A), guanine (G), cytosine (C), and thymine (T). Uracil (U) replaces thymine in RNA. C, T, and U have single-ring structures and are pyrimidines. A and G have double-ring structures and are purines. • The nucleotides in DNA and RNA are joined by phosphodiester linkages involving the sugar of one nucleotide and the phosphate of the next, forming a nucleic acid polymer. Review Figure 4.2, ACTIVITY 4.1 • Complementary base pairing due to hydrogen bonds between A and T, A and U, and G and C occurs in nucleic acids. In RNA, the hydrogen bonds result in a folded molecule. In DNA, the hydrogen bonds connect two strands into a double helix. Review Figures 4.3, 4.4, ACTIVITY 4.2 • The information content of DNA and RNA resides in their base sequences. • DNA is expressed as RNA in transcription. RNA can then specify the amino acid sequence of a protein in translation. Review Figure 4.5

4.2 How and Where Did the Small Molecules of Life Originate? • Historically, many cultures believed that life originated repeatedly by spontaneous generation. This was disproven experimentally. Review Figure 4.6, ANIMATED TUTORIAL 4.1 • A prerequisite for life is the presence of water. • Some meteorites that have landed on Earth contain organic molecules, suggesting that life might have originated extra terrestrially. • An alternative hypothesis is chemical evolution: the idea that organic molecules were formed on Earth before life began. • Chemical experiments modeling the prebiotic conditions on Earth support the idea of chemical evolution. Review Figure 4.8, ANIMATED TUTORIAL 4.2

4.3 How Did the Large Molecules of Life Originate? • Chemical evolution may have led to the polymerization of small molecules into polymers. This may have occurred on the surfaces of clay particles, in hydrothermal vents, or in hot pools at the edges of oceans. • A catalyst speeds up a chemical reaction. Today most catalysts are proteins, but some RNA molecules can function as both catalysts and information molecules. A catalytic RNA is called a ribozyme. • The existence of ribozymes supports the idea of an "RNA world"—a world before DNA. On early Earth, RNA may have acted as a catalyst for its own replication as well as for the synthesis of proteins. DNA could eventually have evolved from RNA. Review Figure 4.9 • In support of the "RNA world" hypothesis, an artificial self-replicating ribozyme was developed in the laboratory. Review Figure 4.10

4.4 How Did the First Cells Originate? • A key to the emergence of living cells was the prebiotic generation of compartments enclosed by membranes. Such enclosed compartments permitted the generation and maintenance of internal chemical conditions that were different from those in the exterior environment. • In the laboratory, fatty acids assemble into protocells that have some of the characteristics of cells. Review Figure 4.11 • Ancient rocks (3.5 billion years old) have been found with imprints that are probably fossils of early cells.

PART TWO, CELLS

CHAPTER 5 Cells: The Working Units of Life

5.1 What Features Make Cells the Fundamental Units of Life? • The cell theory is the unifying theory of cell biology. All living things are composed of cells, and all cells come from preexisting cells. • A cell is small in order to maintain a large surface area-to-volume ratio. This allows it to exchange adequate quantities of materials with its environment. Review Figures 5.1, 5.2, ACTIVITY 5.1 • Cell structures can be studied with light and electron microscopes. Review Figure 5.3, ACTIVITY 5.2 • All cells are enclosed by a selectively permeable plasma membrane that separates their contents from the external environment. • Whereas certain biochemical processes, molecules, and structures are shared by all kinds of cells, there are two categories of organisms—prokaryotes and eukaryotes—that can be distinguished by characteristic cell structures. • Eukaryotic cells are generally larger and more complex than prokaryotic cells. They contain membrane-bound organelles, including the nucleus.

5.2 What Features Characterize Prokaryotic Cells? • Prokaryotic cells have no internal compartments but have a nucleoid region containing DNA, and a cytoplasm containing cytosol, ribosomes, proteins, and small molecules. Some prokaryotes have additional protective structures, including a cell wall, an outer membrane, and a capsule. Review Figure 5.4 • Some prokaryotes have folded internal membranes

such as those used in photosynthesis, and some have flagella or pili for motility or attachment. Review Figure 5.5 • Filamentous proteins in the cytoplasm make up the cytoskeleton, which assists in cell division and the maintenance of cell shape.

5.3 What Features Characterize Eukaryotic Cells? See ANIMATED TUTORIAL 5.1 • Eukaryotic cells are larger than prokaryotic cells and contain many membrane-enclosed organelles. The membranes that envelop organelles ensure compartmentalization of their functions. Review Figure 5.7 • The nucleus contains most of the cell's DNA and participates in the control of protein synthesis. The DNA and the proteins associated with it form a material called chromatin. Each long, thin DNA molecule occurs in a discrete chromatin structure called a chromosome. Review Figure 5.8 • Within the nucleus is the nucleolus, where ribosome assembly begins. After partial assembly, the ribosomes are transported to the cytoplasm, where they are completed and function as sites of protein synthesis. • The endomembrane system—consisting of the endoplasmic reticulum and the Golgi apparatus—is a series of interrelated compartments enclosed by membranes. It segregates proteins and modifies them. Lysosomes contain many digestive enzymes. Review Figures 5.9, 5.10, ACTIVITY 5.3, ANIMATED TUTORIAL 5.2 • Mitochondria and chloroplasts are semiautonomous organelles that process energy. Mitochondria are present in most eukaryotic organisms and contain the enzymes needed for cellular respiration. The cells of photosynthetic eukaryotes contain chloroplasts that harvest light energy for photosynthesis. Review Figures 5.11, 5.12 • Large vacuoles are present in many plant cells. A vacuole consists of a membrane-enclosed compartment full of water and dissolved substances. • The microfilaments, intermediate filaments, and microtubules of the cytoskeleton provide the cell with shape, strength, and movement. Review Figure 5.14 • Motor proteins use cellular energy to change shape and move. They drive the bending movements of cilia and flagella, and transport organelles along microtubules within the cell. Review Figures 5.18, 5.19

5.4 What Are the Roles of Extracellular Structures? • The plant cell wall consists principally of cellulose. Cell walls are pierced by plasmodesmata that join the cytoplasms of adjacent cells. • In animals, the extracellular matrix consists of different kinds of proteins, including collagen and proteoglycans. Review Figure 5.22

5.5 How Did Eukaryotic Cells Originate? • Infoldings of the plasma membrane could have led to the formation of some membrane-enclosed organelles, such as the endomembrane system and the nucleus. Review Figure 5.23A • Symbiosis means "living together." The endosymbiosis theory states that mitochondria and chloroplasts originated when larger cells engulfed, but did not digest, smaller cells. Mutual benefits permitted this symbiotic relationship to be maintained, allowing the smaller cells to evolve into the eukaryotic organelles observed today. Review Figure 5.23B

CHAPTER 6 Cell Membranes

6.1 What Is the Structure of a Biological Membrane? • Biological membranes consist of lipids, proteins, and carbohydrates. The fluid mosaic model of membrane structure describes a phospholipid bilayer in which proteins can move about within the plane of the membrane. Review ACTIVITY 6.1 • The two layers of a membrane may have different properties because of their different lipid compositions. Animal cell membranes may contain high concentrations (up to 25%) of cholesterol. Review ANIMATED TUTORIAL 6.1 • The properties of membranes also depend on the integral membrane proteins and

peripheral membrane proteins associated with them. Some proteins, called transmembrane proteins, span the membrane. Review Figure 6.1 • Carbohydrates, attached to proteins in glycoproteins or to phospholipids in glycolipids, project from the external surface of the plasma membrane and function as recognition signals. • Membranes are not static structures, but are constantly forming, exchanging components, and breaking down.

6.2 How Is the Plasma Membrane Involved in Cell Adhesion and Recognition? • In order for cells to assemble into tissues, they must recognize and adhere to one another. Cell recognition and cell adhesion depend on membrane-associated proteins and carbohydrates. Review Figure 6.6 • Adhesion can involve binding between identical (homotypic) or different (heterotypic) molecules on adjacent cells. • Cell junctions connect adjacent cells. Tight junctions prevent the passage of molecules through the intercellular spaces between cells, and they restrict the migration of membrane proteins over the cell surface. Desmosomes cause cells to adhere firmly to one another. Gap junctions provide channels for communication between adjacent cells. Review Figure 6.7, ACTIVITY 6.2 • Integrins mediate the attachment of animal cells to the extracellular matrix. Detachment and recycling of integrins allow cells to move. Review Figure 6.8

6.3 What Are the Passive Processes of Membrane Transport? See ANIMATED TUTORIAL 6.2 • Membranes exhibit selective permeability, regulating which substances pass through them. Substances can cross the membrane by either passive transport, which requires no input of chemical energy, or active transport, which uses chemical energy. • Diffusion is the movement of a solute from a region of higher concentration to a region of lower concentration. Equilibrium is reached when there is no further net change in concentration. • In osmosis, water diffuses across a membrane from a region of higher water concentration to a region of lower water concentration. • Most cells are in an isotonic environment, where total solute concentrations on both sides of the plasma membrane are equal. If the solution surrounding a cell is hypotonic to the cell interior, more water enters the cell than leaves it, causing it to swell. In plant cells, this contributes to turgor pressure. In a hypertonic solution, more water leaves the cell than enters it, causing it to shrivel. Review Figure 6.9 • A substance can diffuse passively across a membrane by either simple diffusion or facilitated diffusion, via a channel protein or a carrier protein. • Ion channels are membrane proteins that allow the rapid facilitated diffusion of ions through membranes. Gated channels can be opened or closed by either chemical ligands or changes in membrane voltage. Review Figure 6.10 • Aquaporins are water channels. Review Figure 6.11 • Carrier proteins bind to polar molecules such as sugars and amino acids and transport them across the membrane. The maximum rate of this type of facilitated diffusion is limited by the number of carrier (transporter) proteins in the membrane. Review Figure 6.12

6.4 What Are the Active Processes of Membrane Transport? See ANIMATED TUTORIAL 6.3 • Active transport requires the use of chemical energy to move substances across membranes against their concentration or electrical gradients. Active transport proteins may be uniporters, symporters, or antiporters. Review Figure 6.13 • In primary active transport, energy from the hydrolysis of ATP is used to move ions into or out of cells. The sodium–potassium pump is an important example. Review Figure 6.14 • Secondary active transport couples the passive movement of one substance down its concentration gradient to the movement of another substance against its concentration gradient. Energy from ATP is used indirectly to establish the concentration gradient that results in the movement of the first substance. Review Figure 6.15

6.5 How Do Large Molecules Enter and Leave a Cell? See ANIMATED TUTORIAL 6.4 • Endocytosis is the transport of macromolecules, large particles, and small cells into eukaryotic cells via the invagination of the plasma membrane and the formation of vesicles. Phagocytosis and pinocytosis are types of endocytosis. Review Figure 6.16A • In exocytosis, materials in vesicles are secreted from the cell when the vesicles fuse with the plasma membrane. Review Figure 6.16B • In receptor-mediated endocytosis, a specific receptor protein on the plasma membrane binds to a particular macromolecule. Review Figure 6.17

CHAPTER 7 Cell Communication and Multicellularity

7.1 What Are Signals, and How Do Cells Respond to Them? • Cells receive many signals from the physical environment and from other cells. Chemical signals are often at very low concentrations. Autocrine signals affect the cells that make them; juxtracrine signals affect adjacent cells; paracrine signals diffuse to and affect nearby cells; and hormones are carried through the circulatory systems of animals or the vascular systems of plants. Review Figure 7.1, ACTIVITY 7.1 • A signal transduction pathway involves the interaction of a signal molecule with a receptor; the transduction of the signal via a series of steps within the cell; and effects on the function of the cell. Review Figure 7.2 • Signal transduction pathways involve regulation of enzymes and transcription factors. A great deal of crosstalk occurs between pathways.

7.2 How Do Signal Receptors Initiate a Cellular Response? • Cells respond to signals only if they have specific receptor proteins that can recognize those signals. • Binding of a signal ligand to its receptor obeys the chemical law of mass action. A key measurement of the strength of binding is the dissociation constant (KD). • Depending on the nature of its signal or ligand, a receptor may be located in the plasma membrane or inside the target cell. Review Figure 7.4 • Receptors located in the plasma membrane include ion channels, protein kinases, and G protein-linked receptors. • Ion channel receptors are "gated." The gate "opens" when the three-dimensional structure of the channel protein is altered by ligand binding. Review Figure 7.5 • Protein kinase receptors catalyze the phosphorylation of themselves and/or other proteins. Review Figure 7.6 • A G protein has three important binding sites, which bind a G protein-linked receptor, GDP or GTP, and an effector protein. A G protein can either activate or inhibit an effector protein. Review Figure 7.7, ANIMATED TUTORIAL 7.1 • Intracellular receptors include certain photoreceptors in plants and steroid hormone receptors in animals. A lipid-soluble ligand such as a steroid hormone may enter the cytoplasm or the nucleus before binding. Many intracellular receptors are transcription factors. Review Figure 7.8

7.3 How Is the Response to a Signal Transduced through the Cell? • A protein kinase cascade amplifies the response to receptor binding. Review Figure 7.10, ANIMATED TUTORIAL 7.2 • Second messengers include cyclic AMP (cAMP), inositol trisphosphate (IP3), diacylglycerol (DAG), and calcium ions. IP3 and DAG are derived from the phospholipid phosphatidyl inositol-bisphosphate (PIP2). • The gas nitric oxide (NO) is involved in signal transduction in human smooth muscle cells. Review Figure 7.15

• Signal transduction can be regulated in several ways. The balance between activating and inactivating the molecules involved determines the ultimate cellular response to a signal. Review Figure 7.16

7.4 How Do Cells Change in Response to Signals? • The cellular responses to signals may include the opening of ion channels, the alteration of enzyme activities, or changes in gene expression. Review Figure 7.17 • Activated enzymes may activate other enzymes in a signal transduction pathway, leading to impressive amplification of a signal. Review Figure 7.18 • Protein kinases covalently add phosphate groups to target proteins; cAMP binds target proteins noncovalently. Both kinds of binding change the target protein's conformation to expose or hide its active site.

7.5 How Do Cells in a Multicellular Organism Communicate Directly? • Many adjacent animal cells can communicate with one another directly through small pores in their plasma membranes called gap junctions. Protein structures called connexons form thin channels between two adjacent cells through which small signal molecules and ions can pass. Review Figure 7.19A • Plant cells are connected by somewhat larger pores called plasmodesmata, which traverse both plasma membranes and cell walls. The desmotubule narrows the opening of the plasmodesma. Review Figure 7.19B • The evolution of cell communication and tissue formation can be inferred from existing organisms, such as certain green algae. Review Figure 7.20 See ACTIVITY 7.2 for a concept review of this chapter.

PART THREE, CELLS AND ENERGY

CHAPTER 8 Energy, Enzymes, and Metabolism

8.1 What Physical Principles Underlie Biological Energy Transformations? • Energy is the capacity to do work. In a biological system, the usable energy is called free energy (G). The unusable energy is entropy (S), a measure of the disorder in the system. • Potential energy is the energy of state or position; it includes the energy stored in chemical bonds. Kinetic energy is the energy of motion; it is the type of energy that can do work. • The laws of thermodynamics apply to living organisms. The first law states that energy cannot be created or destroyed. The second law states that energy transformations decrease the amount of energy available to do work (free energy) and increase disorder. Review Figure 8.2 • The change in free energy (ΔG) of a reaction determines its point of chemical equilibrium, at which the forward and reverse reactions proceed at the same rate. • An exergonic reaction releases free energy and has a negative ΔG. An endergonic reaction consumes or requires free energy and has a positive ΔG. Endergonic reactions proceed only if free energy is provided. Review Figure 8.3 • Metabolism is the sum of all the biochemical (metabolic) reactions in an organism. Catabolic reactions are associated with the breakdown of complex molecules and release energy (are exergonic). Anabolic reactions build complexity in the cell and are endergonic.

8.2 What Is the Role of ATP in Biochemical Energetics? • Adenosine triphosphate (ATP) serves as an energy currency in cells. Hydrolysis of ATP releases a relatively large amount of free energy. • The ATP cycle couples exergonic and endergonic reactions, harvesting free energy from exergonic reactions, and providing free energy for endergonic reactions. Review Figure 8.6, ACTIVITY 8.1

8.3 What Are Enzymes? • The rate of a chemical reaction is independent of ΔG but is determined by the energy barrier. Review Figure 8.8 • Enzymes are protein catalysts that affect the rates of biological reactions by lowering the energy barrier, supplying the activation energy (Ea) needed to initiate reactions. Review Figure 8.10, ACTIVITY 8.2 • A substrate binds to the enzyme's active site—the site of

catalysis—forming an enzyme–substrate (ES) complex. Enzymes are highly specific for their substrates. Review Figure 8.9

8.4 How Do Enzymes Work? • At the active site, a substrate can be oriented correctly, chemically modified, or strained. As a result, the substrate readily forms its transition state, and the reaction proceeds. Review Figure 8.11 • Binding substrate causes many enzymes to change shape, exposing their active site(s) and allowing catalysis. The change in enzyme shape caused by substrate binding is known as induced fit. Review Figure 8.12 • Some enzymes require other substances, known as cofactors, to carry out catalysis. Prosthetic groups are permanently bound to enzymes; coenzymes are not. A coenzyme can be considered a substrate, as it is changed by the reaction and then released from the enzyme. • Substrate concentration affects the rate of an enzyme-catalyzed reaction.

8.5 How Are Enzyme Activities Regulated? • Metabolism is organized into pathways in which the product of one reaction is a reactant for the next reaction. Each reaction in the pathway is catalyzed by a different enzyme. • Enzyme activity is subject to regulation. Some inhibitors bind irreversibly to enzymes. Others bind reversibly. Review Figures 8.15, 8.16, ANIMATED TUTORIAL 8.1 • An allosteric effector binds to a site other than the active site and stabilizes the active or inactive form of an enzyme. Review Figure 8.17, ANIMATED TUTORIAL 8.2 • The end product of a metabolic pathway may inhibit an enzyme that catalyzes the commitment step of that pathway. Review Figure 8.18 • Reversible phosphorylation is another important mechanism for regulating enzyme activity. • Enzymes are sensitive to their environments. Both pH and temperature affect enzyme activity. Review Figures 8.19, 8.2

CHAPTER 9 Pathways That Harvest Chemical Energy

9.1 How Does Glucose Oxidation Release Chemical Energy? • As a material is oxidized, the electrons it loses are transferred to another material, which is thereby reduced. Such redox reactions transfer large amounts of energy. Review Figure 9.2 • The coenzyme NAD+ is a key electron carrier in biological redox reactions. It exists in two forms, one oxidized (NAD+) and the other reduced (NADH). • Glycolysis does not use O2. Under aerobic conditions, cellular respiration continues the process of breaking down glucose. Under anaerobic conditions, fermentation occurs. Review Figure 9.4, ACTIVITIES 9.1, 9.2 • The pathways of cellular respiration after glycolysis are pyruvate oxidation, the citric acid cycle, and the electron transport/ATP synthesis.

9.2 What Are the Aerobic Pathways of Glucose Catabolism? • Glycolysis consists of ten enzyme-catalyzed reactions that occur in the cell cytoplasm. Two pyruvate molecules are produced for each partially oxidized molecule of glucose, providing the starting material for both cellular respiration and fermentation. Review Figure 9.5 • Pyruvate oxidation follows glycolysis and links glycolysis to the citric acid cycle. This pathway converts pyruvate into acetyl CoA. • Acetyl CoA is the starting point of the citric acid cycle. It reacts with oxaloacetate to produce citrate. A series of eight enzyme catalyzed reactions oxidize citrate and regenerate oxaloacetate, continuing the cycle. Review Figure 9.6, ACTIVITY 9.3

9.3 How Does Oxidative Phosphorylation Form ATP? • Oxidation of electron carriers in the presence of O2 releases energy that can be used to form ATP in a process called oxidative phosphorylation. • The NADH and FADH2 produced in glycolysis, pyruvate oxidation, and the citric acid cycle are oxidized by the

respiratory chain, regenerating NAD+ and FAD. Oxygen (O_2) is the final acceptor of electrons and protons, forming water (H_2O). Review Figure 9.7, ACTIVITY 9.4 • The respiratory chain not only transports electrons, but also transfers protons across the inner mitochondrial membrane, creating the proton-motive force. • Protons driven by the proton-motive force can return to the mitochondrial matrix via ATP synthase, a molecular motor that couples this movement of protons to the synthesis of ATP. This process is called chemiosmosis. Review Figure 9.8, ANIMATED TUTORIALS 9.1, 9.2

Incomplete transfer of electrons can result in the formation of toxic super oxides and hydroxyl radicals. Special enzymes remove them to protect the cell from damage.

9.4 How Is Energy Harvested from Glucose in the Absence of Oxygen? • In the absence of O_2, glycolysis is followed by fermentation. Together, these pathways partially oxidize pyruvate and generate end products such as lactic acid or ethanol. In the process, NAD+ is regenerated from NADH so that glycolysis can continue, thus generating a small amount of ATP. Review Figure 9.11 • For each molecule of glucose used, glycolysis plus fermentation yields two molecules of ATP. In contrast, glycolysis operating with pyruvate oxidation, the citric acid cycle, and the respiratory chain/ ATP synthase yields up to 32 molecules of ATP per molecule of glucose. Review Figure 9.12, ACTIVITY 9.5

9.5 How Are Metabolic Pathways Interrelated and Regulated? • The catabolic pathways for the breakdown of carbohydrates, fats, and proteins feed into the energy-harvesting metabolic pathways. Review Figure 9.13 • Anabolic pathways use intermediate components of the energy harvesting pathways to synthesize fats, amino acids, and other essential building blocks. • The formation of glucose from intermediates of glycolysis and the citric acid cycle is called gluconeogenesis. • The rates of glycolysis and the citric acid cycle are controlled by allosteric regulation and by the diversion of excess acetyl CoA into fatty acid synthesis. Key regulated enzymes include phosphofructokinase, citrate synthase, isocitrate dehydrogenase, and fatty acid synthase. See Figure 9.16, ACTIVITY 9.6

CHAPTER 10 Photosynthesis: Energy from Sunlight

10.1 What Is Photosynthesis? • In the process of photosynthesis, the energy of sunlight is captured and used to convert CO_2 into more complex carbon containing compounds. See ANIMATED TUTORIAL 10.1 • Plants, algae, and cyanobacteria live in aerobic environments and carry out oxygenic photosynthesis: the conversion of CO_2 and H_2O into carbohydrates. • Some bacteria that live in anaerobic environments carry out anoxygenic photosynthesis, in which energy from the sun is used to fix CO_2 without the use of H_2O and the production of O_2. • The light reactions of photosynthesis convert light energy into chemical energy. They produce ATP and reduce NADP+ to NADPH. Review Figure 10.3 • The light-independent reactions do not use light directly but instead use ATP and NADPH to reduce CO_2, forming carbohydrates.

10.2 How Does Photosynthesis Convert Light Energy into Chemical Energy? • Light is a form of electromagnetic radiation. It is emitted in particle-like packets called photons but has wavelike properties. • Molecules that absorb light in the visible spectrum are called pigments. Photosynthetic organisms have several pigments, most notably chlorophylls, but also accessory pigments such as carotenoids and phycobilins. • Absorption of a photon 5puts an electron of a pigment molecule in an excited state that has more energy than its ground state. • Each pigment has a characteristic absorption

spectrum. An action spectrum reflects the rate of photosynthesis carried out by a photosynthetic organism at a given wavelength of light. Review Figure 10.5 • The pigments in photosynthetic organisms are arranged into light-harvesting complexes that absorb energy from light and funnel this energy to chlorophyll a molecules in the reaction center of the photosystem. Chlorophyll can act as a reducing agent, transferring excited electrons to other molecules. Review Figure 10.7 • Noncyclic electron transport uses photosystems I and II to produce ATP, NADPH, and O2. Cyclic electron transport uses only photosystem I and produces only ATP. Both systems generate ATP via the electron transport chain. Review Figures 10.8, 10.9 • Chemiosmosis is the mechanism of ATP production in photophosphorylation. Review Figure 10.10, ANIMATED TUTORIAL 10.2

10.3 How Is Chemical Energy Used to Synthesize Carbohydrates? • The Calvin cycle makes carbohydrates from CO2. The cycle consists of three processes: fixation of CO2, reduction and carbohydrate production, and regeneration of RuBP. See ANIMATED TUTORIAL 10.3 • RuBP is the initial CO2 acceptor, and 3PG is the first stable product of CO2 fixation. The enzyme rubisco catalyzes the reaction of CO2 and RuBP to form 3PG. Review Figure 10.12 • ATP and NADPH formed by the light reactions are used in the reduction of 3PG to form G3P. Review Figure 10.13, ACTIVITY 10.1 • Light stimulates enzymes in the Calvin cycle, further integrating the light-dependent and light-independent pathways. Review Figure 10.14

10.4 How Have Plants Adapted Photosynthesis to Environmental Conditions? • Rubisco can catalyze a reaction between O2 and RuBP in addition to the reaction between CO2 and RuBP. At high temperatures and low CO2 concentrations, the oxygenase function of rubisco is favored over its carboxylase function. • The oxygenase reaction catalyzed by rubisco significantly reduces the efficiency of photosynthesis. The subsequent reactions of photorespiration recover some of the fixed carbon that otherwise would be lost. Review Figure 10.15 • In C4 plants, CO2 reacts with phosphoenolpyruvate (PEP) to form a four-carbon intermediate in mesophyll cells. The four-carbon product releases its CO2 to rubisco in the bundle sheath cells in the interior of the leaf. Review Figures 10.16, 10.17, ACTIVITY 10.2 • CAM plants operate much like C4 plants, but their initial CO2 fixation by PEP carboxylase is temporally separated from the Calvin cycle, rather than spatially separated as in C4 plants.

10.5 How Does Photosynthesis Interact with Other Pathways? • Photosynthesis and cellular respiration are linked through the Calvin cycle, the citric acid cycle, and glycolysis. Review Figure 10.18 • To survive, a plant must photosynthesize more than it respires. • Photosynthesis uses only a small portion of the energy of sunlight. Review Figure 10.19

PART FOUR, GENES AND HEREDITY

CHAPTER 11 The Cell Cycle and Cell Division

11.1 How Do Prokaryotic and Eukaryotic Cells Divide? • Cell division is necessary for the reproduction, growth, and repair of organisms. • Cell division must be initiated by a reproductive signal. Before a cell can divide, the genetic material (DNA) must be replicated and segregated to separate portions of the cell. Cytokinesis then divides the cytoplasm into two cells. • In prokaryotes, most cellular DNA is a single molecule, usually in the form of a circular chromosome. Prokaryotes reproduce by binary fission. Review

Figure 11.2 • In eukaryotes, cells divide by either mitosis or meiosis. Eukaryotic cell division follows the same general pattern as binary fission, but with significant differences. For example, a eukaryotic cell has a distinct nucleus whose chromosomes must be replicated prior to separating the two daughter cells.

11.2 How Is Eukaryotic Cell Division Controlled? • The eukaryotic cell cycle has two main phases: interphase, during which cells are not dividing and the DNA is replicating, and mitosis or M phase, when the cells are dividing. • During most of the eukaryotic cell cycle, the cell is in interphase, which is divided into three subphases: S, G1, and G2. DNA is replicated during S phase. Mitosis (M phase) and cytokinesis follow. Review Figure 11.3 • Cyclin–Cdk complexes regulate the passage of cells through checkpoints in the cell cycle. Retinoblastoma protein (RB) inhibits the cell cycle at the restriction point. The cyclin–Cdk functions by inactivating RB and allows the cell cycle to progress. Review Figures 11.5, 11.6 • External controls such as growth factors can stimulate the cell to begin a division cycle

11.3 What Happens during Mitosis? See ANIMATED TUTORIAL 11.1 • In mitosis, a single nucleus gives rise to two nuclei that are genetically identical to each other and to the parent nucleus. • DNA is wrapped around proteins called histones, forming beadlike units called nucleosomes. A eukaryotic chromosome contains strings of nucleosomes bound to proteins in a complex called chromatin. Review Figure 11.9 • At mitosis, the replicated chromosomes (sister chromatids) are held together at the centromere. Each chromatid consists of one double-stranded DNA molecule. During mitosis sister chromatids, attached by cohesin, line up at the equatorial plate and attach to the spindle apparatus. The chromatids separate (becoming daughter chromosomes) and migrate to opposite ends of the cell. Review Figures 11.10, 11.11, ACTIVITIES 11.1, 11.2 • Mitosis can be divided into several phases called prophase, prometaphase, metaphase, anaphase, and telophase. • Nuclear division is usually followed by cytokinesis. Animal cell cytoplasms divide via a contractile ring made up of actin microfilaments and myosin. In plant cells, cytokinesis is accomplished by vesicles that fuse to form a cell plate. Review Figure 11.13

11.4 What Role Does Cell Division Play in a Sexual Life Cycle? • Asexual reproduction produces clones, new organisms that are genetically identical to the parent. Any genetic variation is the result of changes in genes. • In sexual reproduction, two haploid gametes—one from each parent—unite in fertilization to form a genetically unique, diploid zygote. Sexual life cycles can be haplontic, diplontic, or involve alternation of generations. Review Figure 11.15, ACTIVITY 11.3 • In non-haplontic sexually reproducing organisms, certain cells in the adult undergo meiosis, a process by which a diploid cell produces haploid gametes. • Each gamete contains one of each homologous pair of chromosomes from the parent.

11.5 What Happens during Meiosis? See ANIMATED TUTORIAL 11.2 • Meiosis consists of two nuclear divisions, meiosis I and meiosis II, that together reduce the chromosome number from diploid to haploid. Meiosis ensures that each haploid cell contains one member of each chromosome pair, and results in four genetically diverse haploid cells, usually gametes. Review Figure 11.16, ACTIVITY 11.4 • In meiosis I, entire chromosomes, each with two chromatids, migrate to the poles. In meiosis II, the sister chromatids separate. • During prophase I, homologous chromosomes undergo synapsis to form pairs in a tetrad. Chromatids can form junctions called chiasmata, and genetic material may be exchanged between the two homologs by crossing over. Review Figures 11.17, 11.18 • Both crossing over during prophase I and independent assortment of the homologs as they separate during anaphase I ensure that the gametes are genetically diverse. • In nondisjunction, two members of a homologous pair of

chromosomes go to the same pole during meiosis I, or two chromatids go to the same pole during meiosis II or mitosis. This leads to one gamete having an extra chromosome and another lacking that chromosome. Review Figure 11.20 • The union between a gamete with an abnormal chromosome number and a normal haploid gamete results in aneuploidy. Such genetic abnormalities can be harmful or lethal to the organism. • The numbers, shapes, and sizes of the metaphase chromosomes constitute the karyotype of an organism. • Polyploids have more than two sets of haploid chromosomes. Sometimes these sets come from different species. Review Figure 11.22

11.6 In a Living Organism, How Do Cells Die? • A cell may die by necrosis, or it may self-destruct by apoptosis, a genetically programmed series of events that includes the fragmentation of its nuclear DNA. • Apoptosis is regulated by external and internal signals. These signals result in activation of a class of enzymes called caspases that hydrolyze proteins in the cell. Review Figure 11.23

11.7 How Does Unregulated Cell Division Lead to Cancer? • Cancer cells divide more rapidly than normal cells and can be metastatic, spreading to distant organs in the body. • Cancer can result from changes in either of two types of proteins that regulate the cell cycle. Oncogene proteins stimulate cell division and are activated in cancer. Tumor suppressor proteins normally inhibit the cell cycle, but in cancer they are inactive. Review Figure 11.25 • Cancer treatment often targets the cell cycle in tumor cells. Review Figure 11.26

CHAPTER 12 Inheritance, Genes, and Chromosomes

12.1 What Are the Mendelian Laws of Inheritance? • Physical features of organisms, or characters, can exist in different forms, or traits. A heritable trait is one that can be passed from parent to offspring. A phenotype is the physical appearance of an organism; a genotype is the genetic constitution of the organism. • The different forms of a gene are called alleles. Organisms that have two identical alleles for a trait are called homozygous; organisms that have two different alleles for a trait are called heterozygous. A gene resides at a particular site on a chromosome called a locus. • Mendel's experiments included reciprocal crosses and monohybrid crosses between true-breeding pea plants. Analysis of his meticulously tabulated data led Mendel to propose a particulate theory of inheritance stating that discrete units (now called genes) are responsible for the inheritance of specific traits, to which both parents contribute equally. • Mendel's first law, the law of segregation, states that when any individual produces gametes, the two copies of a gene separate, so that each gamete receives only one member of the pair. Thus every individual in the F1 inherits one copy from each parent. Review Figures 12.3, 12.4 • Mendel used a test cross to find out whether an individual showing a dominant phenotype was homozygous or heterozygous. Review Figure 12.5, ACTIVITY 12.1 • Mendel's use of dihybrid crosses to study the inheritance of two characters led to his second law: the law of independent assortment. The independent assortment of genes in meiosis leads to nonparental combinations of phenotypes in the offspring of a dihybrid cross. Review Figures 12.6, 12.7, ANIMATED TUTORIAL 12.1 • Probability calculations and pedigrees help geneticists trace Mendelian inheritance patterns. Review Figures 12.8, 12.9, ANIMATED TUTORIAL 12.2

12.2 How Do Alleles Interact? • New alleles arise by random mutation. Many genes have multiple alleles. A wild-type allele gives rise to the predominant form of a trait. When the wild-type allele is present at a locus less than 99 percent of the time, the locus is said to be polymorphic. Review Figure

12.10 • In incomplete dominance, neither of two alleles is dominant. The heterozygous phenotype is intermediate between the homozygous phenotypes. Review Figure 12.11 • Codominance exists when two alleles at a locus produce two different phenotypes that both appear in heterozygotes. • An allele that affects more than one trait is said to be pleiotropic.

12.3 How Do Genes Interact? • In epistasis, one gene affects the expression of another. Review Figure 12.13 • Environmental conditions can affect the expression of a genotype. • Penetrance is the proportion of individuals in a group with a given genotype that show the expected phenotype. Expressivity is the degree to which a genotype is expressed in an individual. • Variations in phenotypes can be qualitative (discrete) or quantitative (graduated, continuous). Most quantitative traits result from the effects of several genes and the environment. Genes that together determine quantitative characters are called quantitative trait loci

12.4 What Is the Relationship between Genes and Chromosomes? See ANIMATED TUTORIAL 12.3 • Each chromosome carries many genes. Genes on the same chromosome are referred to as a linkage group. • Genes on the same chromosome can recombine by crossing over. The resulting recombinant chromosomes have new combinations of alleles. Review Figures 12.18, 12.19 • Sex chromosomes carry genes that determine whether the organism will produce male or female gametes. All other chromosomes are called autosomes. The specific functions of sex chromosomes differ among different groups of organisms. • Primary sex determination in mammals is usually a function of the presence or absence of the SRY gene. Secondary sex characteristics are the outward manifestations of maleness and femaleness. • In fruit flies and mammals, the X chromosome carries many genes, but the Y chromosome has only a few. Males have only one allele (are hemizygous) for X-linked genes, so recessive sex-linked mutations are expressed phenotypically more often in males than in females. Females may be unaffected carriers of such alleles. Review Figure 12.21

12.5 What Are the Effects of Genes Outside the Nucleus? • Cytoplasmic organelles such as plastids and mitochondria contain small numbers of genes. In many organisms, cytoplasmic genes are inherited only from the mother because the male gamete contributes only its nucleus (i.e., no cytoplasm) to the zygote at fertilization. Review Figure 12.22

12.6 How Do Prokaryotes Transmit Genes? • Prokaryotes reproduce primarily asexually but can exchange genes in a sexual process called conjugation. Review Figure 12.23 • Plasmids are small, extra chromosomes in bacteria that carry genes involved in important metabolic processes and that can be transmitted from one cell to another. Review Figure 12.24 See ACTIVITIES 12.2, 12.3 for a concept review of this chapter

CHAPTER 13 DNA and Its Role in Heredity

13.1 What Is the Evidence that the Gene Is DNA? • Griffith's experiments in the 1920s demonstrated that some substance in cells can cause heritable changes in other cells. Review Figure 13.1 • The location and quantity of DNA in the cell suggested that DNA might be the genetic material. Avery and his colleagues isolated the transforming principle from bacteria and identified it as DNA. Review Figure 13.2 • The Hershey–Chase experiments established conclusively that DNA (and not protein) is the genetic material, by tracing the DNA of radioactively labeled viruses, with which they infected bacterial cells.

Review Figure 13.4, ANIMATED TUTORIAL 13.1 • Genetic transformation of eukaryotic cells is often called transfection. Transformation and transfection can be studied with the aid of a genetic marker gene that confers a known and observable phenotype. Review Figure 13.5

13.2 What Is the Structure of DNA? • Chargaff's rule states that the amount of adenine in DNA is equal to the amount of thymine, and that the amount of guanine is equal to the amount of cytosine; thus the total abundance of purines (A + G) equals the total abundance of pyrimidines (T + C). • X-ray crystallography showed that the DNA molecule is a double helix. Watson and Crick proposed that the two strands in DNA are antiparallel. Review Figure 13.7 • Complementary base pairing between A and T and between G and C accounts for Chargaff's rule. The bases are held together by hydrogen bonding. • Reactive groups are exposed in the paired bases, allowing for recognition by other molecules such as proteins. Review Figure 13.8

13.3 How Is DNA Replicated? See ANIMATED TUTORIAL 13.2 • Meselson and Stahl showed that DNA undergoes semiconservative replication. Each parent strand acts as a template for the synthesis of a new strand; thus the two replicated DNA molecules each contain one parent strand and one newly synthesized strand. Review Figure 13.10, ANIMATED TUTORIAL 13.3 • In DNA replication, the enzyme DNA polymerase catalyzes the addition of nucleotides to the 3' end of each strand. Which nucleotides are added is determined by complementary base pairing with the template strand. Review Figure 13.11 • The pre-replication complex is a huge protein complex that attaches to the chromosome at the origin of replication (ori). • Replication proceeds from the origin of replication on both strands in the 5'-to-3' direction, forming a replication fork. Review Figure 13.12 • Primase catalyzes the synthesis of a short RNA primer to which nucleotides are added by DNA polymerase. Review Figure 13.13 • Many proteins assist in DNA replication. DNA helicase separates the strands, and single-strand binding proteins keep the strands from reassociating. Review Figure 13.15, ACTIVITY 13.1 • The leading strand is synthesized continuously and the lagging strand in pieces called Okazaki fragments. The fragments are joined together by DNA ligase. Review Figures 13.16, 13.17, ANIMATED TUTORIAL 13.4 • The speed with which DNA polymerization proceeds is attributed to the processive nature of DNA polymerases, which can catalyze many polymerizations at a time. A sliding DNA clamp helps ensure the stability of this process. Review Figure 13.18 • At the ends of eukaryotic chromosomes are regions of repetitive DNA sequence called telomeres. Unless the enzyme telomerase is present, a short segment at the end of each telomere is lost each time the DNA is replicated. After multiple cell cycles, the telomeres shorten enough to cause chromosome instability and cell death. Review Figure 13.19

13.4 How Are Errors in DNA repaired? • DNA polymerases make about one error in 105 bases replicated. DNA is also subject to natural alterations and chemical damage. DNA can be repaired by at least three different mechanisms, including proofreading, mismatch repair, and excision repair. Review Figure 13.20

13.5 How Does the Polymerase Chain Reaction Amplify DNA? • The polymerase chain reaction technique uses DNA polymerase to make multiple copies of DNA in the laboratory. Review Figure 13.21, ANIMATED TUTORIAL 13.5

CHAPTER 14 From DNA to Protein: Gene Expression

14.1 What Is the Evidence that Genes Code for Proteins? • Experiments on metabolic enzymes in the bread mold Neurospora led to the one-gene, one-enzyme hypothesis. We now know that there is a one-gene, one-polypeptide relationship. Review Figure 14.1

14.2 How Does Information Flow from Genes to Proteins? • The central dogma of molecular biology states that DNA encodes RNA, and RNA encodes proteins. Proteins do not encode proteins, RNA, or DNA. • The process by which the information in DNA is copied to RNA is called transcription. The process by which a protein is built from the information in RNA is called translation. Review Figure 14.2, ACTIVITY 14.1 • A product of transcription is messenger RNA (mRNA). Transfer RNAs (tRNAs) translate the genetic information in the mRNA into a corresponding sequence of amino acids to produce a polypeptide. • Certain RNA viruses are exceptions to the central dogma. For example, retroviruses synthesize DNA from RNA in a process called reverse transcription.

14.3 How Is the Information Content in DNA Transcribed to Produce RNA? • In a given gene, only one of the two strands of DNA (the template strand) acts as a template for transcription. RNA polymerase is the catalyst for transcription. • RNA transcription from DNA proceeds in three steps: initiation, elongation, and termination. Review Figure 14.4, ANIMATED TUTORIAL 14.1 • Initiation requires a promoter, to which RNA polymerase binds. Part of each promoter is the initiation site, where transcription begins. • Elongation of the RNA molecule proceeds from the 5′ to 3′ end

• Particular base sequences specify termination, at which point transcription ends and the RNA transcript separates from the DNA template. • The genetic code is a "language" of triplets of mRNA nucleotide bases (codons) corresponding to 20 specific amino acids; there are start and stop codons as well. The code is redundant (an amino acid may be represented by more than one codon) but not ambiguous (no single codon represents more than one amino acid). Review Figures 14.5, 14.6, ANIMATED TUTORIAL 14.2, ACTIVITY 14.2

14.4 How Is Eukaryotic DNA Transcribed and the RNA Processed? • Unlike prokaryotes, where transcription and translation occur in the cytoplasm and are coupled, in eukaryotes transcription occurs in the nucleus and translation occurs later in the cytoplasm. • Eukaryotic genes contain introns, which are noncoding sequences within the transcribed regions of genes. Review Figures 14.7B, 14.8 • The initial transcript of a eukaryotic protein-coding gene is modified with a 5′ cap and a 3′ poly A tail. Review Figure 14.9 • Pre-mRNA introns are removed in the nucleus via RNA splicing by the small nuclear ribonucleoprotein particles. Then the mRNA passes through a nuclear pore into the cytoplasm, where it is translated through ribosomes. Review Figure 14.10, ANIMATED TUTORIAL 14.3

14.5 How Is RNA Translated into Proteins? See ANIMATED TUTORIAL 14.4 • During translation, amino acids are linked together in the order specified by the codons in the mRNA. This task is achieved by tRNAs, which bind to (are charged with) specific amino acids. • Each tRNA species has an amino acid attachment site as well as an anticodon complementary to a specific mRNA codon. A specific activating enzyme charges each tRNA with its specific amino acid. Review Figures 14.11, 14.12 • The ribosome is the molecular workbench where translation takes place. It has one large and one small subunit, both made of ribosomal RNA and proteins. • Three sites on the large subunit of the ribosome interact with tRNA anticodons. The A site is where the charged tRNA anticodon binds to the mRNA codon; the P site is where the tRNA adds its amino acid to the growing polypeptide chain; and the E site is where the tRNA is released. Review Figure 14.13 • Translation occurs in three steps: initiation, elongation, and termination. The initiation complex consists of tRNA bearing the first amino acid, the small ribosomal

subunit, and mRNA. A specific complementary sequence on the small subunit rRNA binds to the transcription initiation site on the mRNA. Review Figure 14.14 • The growing polypeptide chain is elongated by the formation of peptide bonds between amino acids, catalyzed by the rRNA. Review Figure 14.15 • When a stop codon reaches the A site, it terminates translation by binding a release factor. Review Figure 14.16 • In a polysome, more than one ribosome moves along a strand of mRNA at one time. Review Figure 14.17

14.6 What Happens to Polypeptides after Translation? • Signal sequences of amino acids direct polypeptides to their cellular destinations. Review Figures 14.18, 14.19 • Destinations in the cytoplasm include organelles, which proteins enter after being recognized and bound by surface receptors. • Proteins "addressed" to the ER bind to a receptor protein in the ER membrane. Review Figure 14.18 • Posttranslational modifications of polypeptides include proteolysis, in which a polypeptide is cut into smaller fragments; glycosylation, in which sugars are added; and phosphorylation, in which phosphate groups are added. Review Figure 14.20

CHAPTER 15 Gene Mutation and Molecular Medicine

15.1 What Are Mutations? • Mutations are heritable changes in DNA. Somatic mutations are passed on to daughter cells, but only germ line mutations are passed on to sexually produced offspring. Review ANIMATED TUTORIAL 15.1 • Point mutations result from alterations in single base pairs of DNA. Silent mutations can occur in noncoding DNA or in coding regions of genes and do not affect the amino acid sequences of proteins. Missense, nonsense, and frame-shift mutations all cause changes in protein sequences. Review Figure 15.2 • Chromosomal mutations (deletions, duplications, inversions, and translocations) involve large regions of chromosomes. Review Figure 15.4 • Spontaneous mutations occur because of instabilities in DNA or chromosomes. Induced mutations occur when a mutagen damages DNA. Review Figure 15.5 • Mutations can occur in hot spots where cytosine has been methylated to 5'-methylcytosine. Review Figure 15.6 • Mutations, although often detrimental to an individual organism, are the raw material of evolution.

15.2 What Kinds of Mutations Lead to Genetic Diseases? • Abnormalities in proteins have been implicated in genetic diseases. • While a single amino acid difference can be the cause of disease, amino acid variations have been detected in many functional proteins. Review Figures 15.7, 15.8 • Point mutations, deletions, and chromosome abnormalities are associated with genetic diseases. Review Figure 15.9 • The effects of fragile-X syndrome worsen with each generation. This pattern is the result of an expanding triplet repeat. Review Figure 15.10 • A series of genetic mutations can lead to colon cancer. Review Figure 15.11 • Multifactorial diseases are caused by the interactions of many genes and proteins with the environment. They are much more common than diseases caused by mutations in a single gene.

15.3 How Are Mutations Detected and Analyzed? • Restriction enzymes, which are made by microorganisms as a defense against viruses, bind to and cut DNA at specific recognition sequences (also called restriction sites). These enzymes can be used to produce small fragments of DNA for study, a technique known as restriction digestion. Review Figure 15.12 • DNA fragments can be separated by size using gel electrophoresis. Review Figure 15.13, ANIMATED TUTORIAL 15.2 • DNA fingerprinting is used to distinguish among specific individuals or to reveal which individuals are most closely related to one

another. It involves the detection of DNA polymorphisms, including single nucleotide polymorphisms (SNPs) and short tandem repeats (STRs). Review Figure 15.14, ACTIVITY 15.1 • It is possible to isolate both the mutant genes and the abnormal proteins responsible for human diseases. Review Figure 15.15 • The goal of the DNA barcoding project is to sequence a single region of DNA in all species for identification purposes.

15.4 How Is Genetic Screening Used to Detect Diseases? • Genetic screening is used to detect human genetic diseases, alleles predisposing people to those diseases, or carriers of those disease alleles. • Genetic screening can be done by looking for abnormal protein expression. Review Figure 15.17 • DNA testing is the direct identification of mutant alleles. Any cell can be tested at any time in the life cycle. Review Figure 15.18, ANIMATED TUTORIAL 15.3

15.5 How Are Genetic Diseases Treated? • There are three ways to modify the phenotype of a genetic disease: restrict the substrate of a deficient enzyme, inhibit a harmful metabolic reaction, or supply a missing protein. Review Figure 15.19 • Cancer sometimes can be treated with treated with metabolic inhibitors. • In gene therapy, a mutant gene is replaced with a normal gene. Both ex vivo and in vivo therapies are being developed. Review Figure 15.20

CHAPTER 16 Regulation of Gene Expression

16.1 How Is Gene Expression Regulated in Prokaryotes? • Some proteins are synthesized only when they are needed. Proteins that are made only in the presence of a particular compound—an inducer—are inducible proteins. Proteins that are made at a constant rate regardless of conditions are constitutive proteins. Review Figure 16.2 • An operon consists of a promoter, an operator, and two or more structural genes. Promoters and operators do not code for proteins, but serve as binding sites for regulatory proteins. Review Figure 16.4 • Regulatory genes code for regulatory proteins, such as repressors. When a repressor binds to an operator, transcription of the structural gene is inhibited. Review Figure 16.5, ANIMATED TUTORIALS 16.1, 16.2 • The lac operon is an example of an inducible system, in which the presence of an inducer (lactose) keeps the repressor from binding the operator, allowing the transcription of structural genes for lactose metabolism. • Transcription can be enhanced by the binding of an activator protein to the promoter. Review Figure 16.6 • Catabolite repression is the inhibition of a catabolic pathway for one energy source by a different, preferred energy source.

16.2 How Is Eukaryotic Gene Transcription Regulated? • Eukaryotic gene expression is regulated both during and after transcription. Review Figure 16.7, ACTIVITY 16.1 • Transcription factors and other proteins bind to DNA and affect the rate of initiation of transcription at the promoter. Review Figures 16.8, 16.9, ANIMATED TUTORIAL 16.3 • The interactions of these proteins with DNA are highly specific and depend on protein domains and DNA sequences. • Genes at distant locations from one another can be coordinately regulated by transcription factors and promoter elements. Review Figure 16.11

16.3 How Do Viruses Regulate Their Gene Expression? • Viruses are not cells, and rely on host cells to reproduce. • The basic unit of a virus is a virion, which consists of a nucleic acid genome (DNA or RNA) and a protein coat, called a capsid. • Bacteriophages are viruses that infect bacteria. • Viruses undergo a lytic cycle, which causes the host cell to burst, releasing new virions. • Some viruses have promoters that bind host RNA polymerase, which they use to transcribe their own genes and proteins. Review

Figure 16.13 • Some viruses can also undergo lysogeny, in which a molecule of their DNA, called a prophage, is inserted into the host chromosome, where it replicates for generations. Review Figure 16.14 • The cellular environment determines whether a phage undergoes a lytic or a lysogenic cycle. Regulatory proteins that compete for promoters on phage DNA control the switch between the two life cycles. Review Figure 16.15 • A retrovirus uses reverse transcriptase to generate a cDNA provirus from its RNA genome. The provirus is incorporated into the host's DNA and can be activated to produce new virions. Review Figure 16.16

16.4 How Do Epigenetic Changes Regulate Gene Expression? • Epigenetics refers to changes in gene expression that do not involve changes in DNA sequences. • Methylation of cytosine residues generally inhibits transcription. Review Figure 16.18 • Modifications of histone proteins in nucleosomes make transcription either easier or more difficult. Review Figure 16.19 • Epigenetic changes can occur because of the environment. • DNA methylation can explain genomic imprinting, where the expression of a gene depends on its parental origin. Review Figure 16.20

16.5 How Is Eukaryotic Gene Expression Regulated after Transcription? • Alternative splicing of pre-mRNA can produce different proteins. Review Figure 16.22 • Small RNAs do not code for proteins but regulate the translation and longevity of mRNA. Review Figure 16.23 • The translation of mRNA to proteins can be regulated by translational repressors. • The proteasome can break down proteins, thus affecting protein longevity. Review Figure 16.25 See ACTIVITY 16.2 for a concept review of this chapter

PART FIVE, GENOMES

CHAPTER 17 Genomes

17.1 How Are Genomes Sequenced? • New methods of DNA sequencing involve miniaturization and computerized analysis. Review Figure 17.1, ANIMATED TUTORIALS 17.1, 17.2 • Genomes are sequenced in overlapping fragments, and then the fragments are lined up to give the final sequence. Review Figure 17.2 • The analysis of genome sequences gives information about protein-coding and noncoding regions. Review Figure 17.3

17.2 What Have We Learned from Sequencing Prokaryotic Genomes? • DNA sequencing is used to study the genomes of prokaryotes that are important to humans and ecosystems. • Metagenomics is the identification of DNA sequences without first isolating, growing, and identifying the organisms present in an environmental sample. Many of these sequences are from prokaryotes that were heretofore unknown to biologists. Review Figure 17.4 • Transposable elements and composite transposons can move about the genome. Review Figure 17.5 • Transposon mutagenesis can be used to inactivate genes one by one. The mutated organism can be tested for survival and an artificial genome created based on a minimal set of essential genes. Review Figures 17.6, 17.7

17.3 What Have We Learned from Sequencing Eukaryotic Genomes? • Genome sequences from model organisms have demonstrated some common features of the eukaryotic genome. In addition, there are specialized genes for cellular compartmentalization, development, and features unique to plants. Review Tables 17.2–17.5, Figures 17.8, 17.9 • Some eukaryotic genes exist as members of gene families.

Proteins may be made from these closely related genes at different times and in different tissues. Some members of gene families may be nonfunctional pseudogenes. Review Figure 17.10 • Repeated sequences are present in the eukaryotic genome. Review Table 17.6 • Moderately repetitive sequences include those coding for rRNA and transposons. Review Figure 17.11

17.4 What Are the Characteristics of the Human Genome? • The haploid human genome has 3.2 billion bp. • Only about 1.2 percent of the genome codes for proteins; the rest consists of repeated sequences and noncoding DNA. • Virtually all human genes have introns, and alternative splicing leads to the production of more than one protein per gene. • SNP genotyping (haplotype mapping) correlates variations in the genome with diseases or drug sensitivity. It may lead to personalized medicine. Review Figure 17.14 • Pharmacogenomics is the analysis of genetics as applied to drug metabolism. Review Figure 17.15

17.5 What Do the New Disciplines of Proteomics and Metabolomics Reveal? • The proteome is the total protein content of an organism. • There are more proteins than there are protein-coding genes in the genome. • The proteome can be analyzed using chemical methods that separate and identify proteins. These include two-dimensional electrophoresis and mass spectrometry. See Figure 17.16 • The metabolome is the total content of small molecules, such as intermediates in primary metabolism, hormones, and secondary metabolites. See ACTIVITY 17.1 for a concept review of this chapter

CHAPTER 18 Recombinant DNA and Biotechnology

18.1 What Is Recombinant DNA? • Recombinant DNA is formed by the combination of two DNA sequences from different sources. Review Figure 18.1 • Many restriction enzymes make staggered cuts in the two strands of DNA, creating fragments that have sticky ends with unpaired bases. • DNA fragments with sticky ends can be used to create recombinant DNA. DNA molecules from different sources can be cut with the same restriction enzyme and spliced together using DNA ligase. Review Figure 18.2

18.2 How Are New Genes Inserted into Cells? • One goal of recombinant DNA technology is to clone a particular gene, either for analysis or to produce its protein product in quantity. • Bacteria, yeasts, and cultured plant and animal cells are commonly used as hosts for recombinant DNA. The insertion of foreign DNA into host cells is called transformation or (for animal cells) transfection. Transformed or transfected cells are called transgenic cells. • Various methods are used to get recombinant DNA into cells. These include chemical or electrical treatment of the cells, the use of viral vectors, and injection. Agrobacterium tumefaciens is often used to insert DNA into plant cells. • To identify host cells that have taken up a foreign gene, the inserted sequence can be tagged with one or more reporter genes, which are genetic markers with easily identifiable phenotypes. Selectable markers allow for the selective growth of transgenic cells. Review Figures 18.3, 18.4 • Replication of the foreign gene in the host cell requires that it become part of a segment of DNA that contains a replicon (origin and terminus of replication). • Vectors are DNA sequences that can carry new DNA into host cells. Plasmids and viruses are commonly used as vectors.

18.3 What Sources of DNA Are Used in Cloning? • DNA fragments from a genome can be inserted into host cells to create a genomic library. Review Figure 18.5A • The mRNAs produced in a certain tissue at a

certain time can be extracted and used to create complementary DNA (cDNA) by reverse transcription. Review Figure 18.5B • PCR products can be used for cloning. Synthetic DNA containing any desired sequence can be made in the laboratory.

18.4 What Other Tools Are Used to Study DNA Function? • Homologous recombination can be used to knock out a gene in a living organism. Review Figure 18.6 • Gene silencing techniques can be used to inactivate the mRNA transcript of a gene, which may provide clues to the gene's function. Artificially created antisense RNA or siRNA can be added to a cell to prevent translation of a specific mRNA. Review Figure 18.7 • DNA microarray technology permits the screening of thousands of cDNA sequences at the same time. Review Figure 18.8, ANIMATED TUTORIAL 18.1

18.5 What Is Biotechnology? • Biotechnology is the use of living cells to produce materials useful to people. Recombinant DNA technology has resulted in a boom in biotechnology. • Expression vectors allow a transgene to be expressed in a host cell. Review Figure 18.9, ACTIVITY 18.1

18.6 How Is Biotechnology Changing Medicine and Agriculture? • Recombinant DNA techniques have been used to make medically useful proteins. Review Figure 18.10 • Pharming is the use of transgenic plants or animals to produce pharmaceuticals. Review Figure 18.11 • Because recombinant DNA technology has several advantages over traditional agricultural biotechnology, it is being extensively applied to agriculture. Review Figure 18.12 • Transgenic crop plants can be adapted to their environments, rather than vice versa. • There is public concern about the application of recombinant DNA technology to food production

CHAPTER 19 Differential Gene Expression in Development

19.1 What Are the Processes of Development? • A multicellular organism begins its development as an embryo. A series of embryonic stages precedes the birth of an independent organism. Review Figure 19.1, ACTIVITY 19.1 • The processes of development are determination, differentiation, morphogenesis, and growth. • Differential gene expression is responsible for the differences among cell types. Cell fate is determined by environmental factors, such as the cell's position in the embryo, as well as by intracellular influences. Review Figure 19.2, ANIMATED TUTORIAL 19.1 • Determination is followed by differentiation, the actual changes in biochemistry, structure, and function that result in cells of different types. Determination is a commitment; differentiation is the realization of that commitment. • Over the course of development, embryo cells decrease in cell potency. Totipotent cells (such as a zygote) are capable of forming every cell type in the adult body. Pluripotent cells can give rise to most cell types, multipotent cells to several cell types, and unipotent cells to only one cell type.

19.2 How Is Cell Fate Determined? • Cytoplasmic segregation—the unequal distribution of cytoplasmic determinants in the egg, zygote, or early embryo—can establish polarity and lead to cell fate determination. Review Figure 19.3, ANIMATED TUTORIAL 19.2 • Induction is a process by which embryonic animal tissues direct the development of neighboring cells and tissues by secreting chemical signals, called inducers. Review Figures 19.4, 19.5

19.3 What Is the Role of Gene Expression in Development? • Inducers act through signaling pathways to determine cell fate. Review Figure 19.6 • Differential gene expression results in cell differentiation. Transcription factors are especially important in regulating gene expression during differentiation. •

Complex interactions of many genes and their products are responsible for differentiation during development. Review Figure 19.7

19.4 How Does Gene Expression Determine Pattern Formation? • Pattern formation is the process that results in the spatial organization of a tissue or organism. • During development, selective elimination of cells by apoptosis results from the expression of specific genes. Review Figure 19.8 • Sepals, petals, stamens, and carpels form in plants as a result of combinatorial interactions between transcription factors encoded by organ identity genes. Review Figure 19.9 • The transcription factors encoded by floral organ identity genes contain an amino acid sequence called the MADS box that can bind to DNA. • Both plants and animals use positional information as a basis for pattern formation. Positional information usually comes in the form of a signal called a morphogen. Different concentrations of the morphogen cause different effects. See Figures 19.10, 19.11 • In the fruit fly D. melanogaster, a cascade of transcriptional activation sets up the axes of the embryo, the development of the segments, and finally the determination of cell fate in each segment. The cascade involves the sequential expression of maternal effect genes, gap genes, pair rule genes, segment polarity genes, and Hox genes. Review Figures 19.13, 19.14, ANIMATED TUTORIAL 19.3 • Hox genes help determine cell fate in the embryos of all animals. The homeobox is a DNA sequence found in Hox genes and other genes that code for transcription factors. The sequence of amino acids encoded by the homeobox is called the homeodomain.

19.5 Is Cell Differentiation Reversible? • The ability to create clones from differentiated cells demonstrates the principle of genomic equivalence. Review Figures 19.16, 19.17 • Stem cells produce daughter cells that differentiate when provided with appropriate intercellular signals. Some multipotent stem cells in the adult body can differentiate into a limited number of cell types to replace dead cells and maintain tissues. Review Figure 19.18 • Embryonic stem cells are pluripotent and can be cultured in the laboratory. Under suitable environmental conditions, these cells can differentiate into almost any tissue type. Induced pluripotent stem cells have similar characteristics. This has led to technologies designed to replace cells or tissues damaged by injury or disease. Review Figure 19.19, ANIMATED TUTORIAL 19.4

CHAPTER 20 Genes, Development, and Evolution

20.1 How Can Small Genetic Changes Result in Large Changes in Phenotype? • Evolutionary developmental biology, or evo-devo, is the study of the evolutionary aspects of development. This field focuses on the molecular mechanisms that underlie the development of phenotypic diversity. • Changes in development underlie evolutionary changes in morphology that produce differences in body forms. • Similarities in the basic mechanisms of development between widely divergent organisms reflect common ancestry. Review Figure 20.1 • Evolutionary diversity is produced using a modest number of regulatory genes. • Genes encoding the transcription factors and other regulatory proteins that govern pattern formation in the developing bodies of multicellular organisms can be thought of as a genetic toolkit. These regulatory genes have been highly conserved throughout evolution. Review Figure 20.2

20.2 How Can Mutations with Large Effects Change Only One Part of the Body? • The bodies of developing and mature organisms are organized into self-contained units, or modules, that can be modified independently. See ANIMATED TUTORIAL 20.1 • The genetic toolkit involves genetic

switches—promoters, enhancers, and repressors—that can alter the expression of developmental genes in different modules independently of one another. • Developmental genes can be expressed in a modular fashion in different amounts (heterometry), at different times (heterochrony), or in different locations (heterotopy). Review Figures 20.3–20.6

20.3 How Can Developmental Changes Result in Differences among Species? • Changes in genetic switches that determine where, when, and to what extent a set of genes will be expressed underlie both the transformation of an individual from egg to adult and the evolution of differences among species. • Morphological differences among species can result from mutations in the genes that regulate the development of modules such as body segments or wings. Review Figures 20.8, 20.9

20.4 How Can the Environment Modulate Development? • The ability of an organism to modify its development in response to environmental conditions is called developmental, or phenotypic, plasticity. • In many species of reptiles, sex development is determined by incubation temperature, which acts through genes that control the production, modification, and action of sex hormones. Review Figure 20.11 • The adaptive significance of developmental plasticity is not always obvious, but experiments can test for effects on reproductive success. Review Figure 20.12 • Some environmental cues, such as those that anticipate seasons, are highly regular and can reliably drive seasonal adaptations in body form and function. Review Figure 20.13 • Environmental cues that trigger developmental change are diverse and can act at any stage of the life of an organism.

20.5 How Do Developmental Genes Constrain Evolution? • Virtually all evolutionary innovations are modifications of preexisting structures. Review Figure 20.15 • Because many genes that govern development have been highly conserved, similar traits are likely to evolve repeatedly, especially among closely related species. This process is called parallel phenotypic evolution. Review Figure 20.16

PART SIX, THE PATTERNS AND PROCESSES OF EVOLUTION

CHAPTER 21 Mechanisms of Evolution

21.1 What Is the Relationship between Fact and Theory in Evolution? • Evolution is genetic change in populations over time. Evolution can be observed directly in living populations as well as in the fossil record of life. • Evolutionary theory refers to our understanding of the mechanisms of evolutionary change. • Charles Darwin in best known for his ideas on the common ancestry of divergent species and on natural selection (the differential survival and reproduction of individuals based on variation in their traits) as a mechanism of evolution. See ANIMATED TUTORIAL 21.1, ACTIVITY 21.1 • Since Darwin's time, many biologists have contributed to the development of evolutionary theory, and rapid progress in our understanding continues today. Review Figure 21.2 • For a population to evolve, its members must possess heritable genetic variation.

21.2 What Are the Mechanisms of Evolutionary Change? • Mutation is the source of the genetic variation on which mechanisms of evolution act. • The term adaptation refers both to a trait that evolves through natural selection and to the process that produces such traits.

• Within populations, natural selection acts to increase the frequency of beneficial alleles (positive selection) and to decrease the frequency of deleterious alleles (purifying selection). • Movement of individuals or gametes between populations results in gene flow. • In small populations, genetic drift—the random loss of individuals and the alleles they possess from one generation to the next— may produce large changes in allele frequencies over time and greatly reduce genetic variation. See ANIMATED TUTORIAL 21.2 • Population bottlenecks occur when only a few individuals survive a random event, resulting in a drastic shift in allele frequencies within the population and the loss of genetic variation. Similarly, a population established by a small number of individuals colonizing a new region may lose genetic variation via a founder effect. Review Figure 21.7 • Nonrandom mating may result in changes in genotype and allele frequencies in a population. • Sexual selection results from differential reproductive success based on individuals' phenotypes. Review Figure 21.9

21.3 How Do Biologists Measure Evolutionary Change? • Allele frequencies measure the amount of genetic variation in a population. Genotype frequencies show how a population's genetic variation is distributed among its members. Together, allele and genotype frequencies describe a population's genetic structure. Review Figure 21.10 • Hardy–Weinberg equilibrium predicts genotype frequencies from allele frequencies in the absence of evolution. Deviation from these frequencies indicates that evolutionary mechanisms are at work. Review Figure 21.11, ANIMATED TUTORIAL 21.3 • Natural selection can act on characters with quantitative variation in three different ways. Review Figure 21.12 • Stabilizing selection acts to reduce variation without changing the mean value of a trait. • Directional selection acts to shift the mean value of a trait toward one extreme. • Disruptive selection favors both extremes of trait values, resulting in a bimodal character distribution.

21.4 How Is Genetic Variation Distributed and Maintained within Populations? • Neutral mutations, sexual recombination, frequency-dependent selection, and heterozygote advantage can all maintain genetic variation within populations. • Neutral alleles do not affect the fitness of an organism, are not affected by natural selection, and may accumulate or be lost by genetic drift. • Despite its short-term disadvantages, sexual reproduction generates countless genotypic combinations that increase the evolutionary potential and survivorship of populations. • A polymorphism may be maintained by frequency-dependent selection when the fitness of a genotype depends on its frequency in a population. • Genetic variation within species may be maintained by the existence of genetically distinct populations over geographic space. A gradual change in phenotype across a geographic gradient is known as clinal variation. Review Figure 21.18

21.5 What Are the Constraints on Evolution? • Developmental processes constrain evolution because all evolutionary innovations are modifications of previously existing structures. • Most adaptations impose costs as well as benefits. An adaptation can evolve only if the benefits it confers exceed the costs it imposes. Review Figure 21.20, ANIMATED TUTORIAL 21.4

CHAPTER 22 Reconstructing and Using Phylogenies

22.1 What Is Phylogeny? • Phylogeny is the history of evolutionary relationships among organisms or their genes. Groups of evolutionarily related species are represented as branches in a phylogenetic tree. Review Figures 22.1, 22.2 • Named species and groups of species are called taxa. A taxon that consists of an ancestor and all of its evolutionary descendants is called a clade. Review Figure 22.3 • Homologies

are similar traits that have been inherited from a common ancestor. Review Figure 22.4 • A derived trait that is shared by two or more taxa and is inherited from their common ancestor is called a synapomorphy. • Distantly related species may show similar traits that do not result from common ancestry. Convergent evolution and evolutionary reversals can give rise to such traits, which are called homoplasies.

22.2 How Are Phylogenetic Trees Constructed? • Phylogenetic trees can be constructed from synapomorphies using the logic of parsimony. Review Figure 22.5, ACTIVITY 22.1, ANIMATED TUTORIAL 22.1 • Sources of phylogenetic information include morphology, patterns of development, the fossil record, behavioral traits, and molecular traits such as DNA and protein sequences. • Phylogenetic trees can also be constructed with maximum likelihood methods, which find the tree most likely to have generated the observed data. • Phylogenetic methods have been tested in both experimental and simulation studies, and have been shown to be accurate under a wide variety of conditions.

22.3 How Do Biologists Use Phylogenetic Trees? • Phylogenetic trees are used to make comparisons among living organisms. Review Figure 22.10 • Phylogenetic trees are used to reconstruct the past and to understand the origin of traits. Review Figure 22.11 • Biologists can use phylogenetic trees to reconstruct ancestral states. See ANIMATED TUTORIAL 22.2 • Phylogenetic trees may include estimates of divergence times of lineages determined by molecular clock analysis. Review Figure 22.13

22.4 How Does Phylogeny Relate to Classification? • Biologists use phylogenetic relationships to organize life into a coherent classification system. • Taxa in modern classifications are expected to be monophyletic groups. Paraphyletic and polyphyletic groups are not considered appropriate taxonomic units. Review Figure 22.15, ACTIVITY 22.2 • Several sets of rules govern the use of scientific names, with the goal of providing unique and universal names for taxa

CHAPTER 23 Speciation

23.1 What Are Species? • Speciation is the divergence of biological lineages and the emergence of reproductive isolation between those lineages. • The morphological species concept distinguishes species on the basis of physical similarities and differences. • The biological species concept distinguishes species on the basis of reproductive isolation. • The lineage species concept recognizes evolutionarily independent lineages as species, allowing biologists to consider species over evolutionary time.

23.2 What Is the Genetic Basis of Speciation? • Speciation usually results from the interruption of gene flow within a population. • The Dobzhansky–Muller model describes how reproductive isolation between two physically isolated populations can develop through the accumulation of incompatible genes or chromosomal arrangements. Review Figures 23.3, 23.4, ANIMATED TUTORIAL 23.1 • Reproductive isolation increases with increasing genetic divergence between populations. Review Figure 23.5

23.3 What Barriers to Gene Flow Result in Speciation? See ANIMATED TUTORIAL 23.2 • Allopatric speciation, which results when populations are separated by a physical barrier, is the dominant mode of speciation in most groups of organisms. This type of speciation may follow founder events, in which some members of a population cross a barrier and found a new, isolated population. Review Figures

23.6–23.8, ANIMATED TUTORIALS 23.2 and 23.3 • Sympatric speciation results when the genomes of two groups diverge in the absence of physical isolation. Such divergence can result from disruptive selection if individuals with different genotypes prefer distinct microhabitats. • Sympatric speciation can occur within two generations via polyploidy. Polyploidy may arise from chromosome duplications within a species (autopolyploidy) or from hybridization that results in combining the chromosomes of two species (allopolyploidy). Review Figure 23.9

23.4 What Happens When Newly Formed Species Come into Contact? • Prezygotic isolating mechanisms prevent hybridization; postzygotic isolating mechanisms reduce the fitness of hybrids. • Postzygotic isolating mechanisms lead to reinforcement of prezygotic isolating mechanisms by natural selection. Review Figures 23.11, 23.12, 23.14 • Hybrid zones may form and persist if reproductive isolation between species is incomplete. Review Figure 23.15

23.5 Why Do Rates of Speciation Vary? • Dietary specialization, pollinator specialization, sexual selection, and dispersal ability all influence speciation rates. Review Figure 23.16 • Evolutionary radiation refers to the rapid proliferation of descendant species from a single ancestor species. This often occurs following colonization, when new species may rapidly move into unoccupied ecological niches in a process known as adaptive radiation. See ACTIVITY 23.1 for a concept review of this chapter

CHAPTER 24 Evolution of Genes and Genomes

24.1 How Are Genomes Used to Study Evolution? • A genome is an organism's full set of genes, regulatory sequences, and structural elements as well as noncoding DNA. • The field of molecular evolution concerns relationships between the structures of genes and proteins and the functions of organisms. • Sequence alignments of proteins or nucleic acids from different organisms allow us to compare the sequences and identify homologous positions. Review Figure 24.1, ACTIVITY 24.1 • The minimum number of changes between sequences can be calculated from a similarity matrix. Models of sequence evolution can be used to account for changes that cannot be observed directly. Review Figure 24.2, ACTIVITY 24.2

24.2 What Do Genomes Reveal about Evolutionary Processes? • Nonsynonymous substitutions of nucleotides result in amino acid replacements in proteins, but synonymous substitutions do not. Review Figure 24.5 • The neutral theory of molecular evolution states that much of the molecular change in nucleotide sequences does not change genome function. The rate of fixation of neutral mutations is independent of population size and is equal to the mutation rate. • Positive selection for change in a protein-coding gene may be detected by a higher rate of nonsynonymous than synonymous substitutions. The reverse is true of purifying selection. • Common selective constraints can lead to convergent evolution of amino acid sequences in distantly related species. Review Figure 24.7 • The total size of genomes varies much more widely across multicellular species than does the number of functional genes. Review Figures 24.8, 24.9

24.3 How Do Genomes Gain and Maintain Functions? • Lateral gene transfer can result in the rapid acquisition of new functions from distantly related species. • Gene duplications can result in increased production of the gene's product, in nonfunctional pseudogenes, or in new gene functions. Several rounds of gene duplication can give rise to multiple genes with related functions, collectively known as a

gene family. Review Figures 24.10, 24.11. • Gene trees describe the evolutionary history of particular genes or gene families. See ACTIVITY 24.3 • Some highly repeated genes undergo concerted evolution, in which the multiple copies within the genome maintain their similarity, even as the genes diverge among species. Review Figure 24.12, ANIMATED TUTORIAL 24.1

24.4 What Are Some Applications of Molecular Evolution? • Orthologs are genes that are related through speciation events, whereas paralogs are genes that are related through gene duplication events. Review Figure 24.13 • Protein function can be studied by examining gene evolution. Detection of positive selection can be used to identify molecular changes that have resulted in functional changes. • In vitro evolution is used to produce synthetic molecules with particular desired functions. Review Figure 24.14 • Many diseases are identified, studied, and combated through molecular evolutionary investigations

CHAPTER 25 The History of Life on Earth

25.1 How Do Scientists Date Ancient Events? • The relative ages of organisms can be determined by the strata of sedimentary rocks in which their fossils are found. • Paleontologists use a variety of radioisotopes with different half-lives to date events at different times in the remote past. Review Figure 25.1 • Geologists divide the history of life into eons, eras, and periods. These divisions are based largely on major differences in the fossil assemblages found in successive layers of rocks. Review Table 25.1

25.2 How Have Earth's Continents and Climates Changed over Time? • Plate tectonic processes result in continental drift as well as volcanism and mountain building. Changes in the positions and sizes of the continents affect oceanic circulation patterns, climate, and sea levels. Review Figure 25.3, ANIMATED TUTORIAL 25.1 • Major physical events on Earth, such as the collision of continents that formed the single gigantic land mass Pangaea, have affected Earth's surface, climate, and atmosphere. In addition, extraterrestrial events such as meteorite strikes have created sudden and dramatic climate shifts. Some dramatic changes in physical conditions on Earth have caused mass extinctions. Review Figure 25.4 • Oxygen-generating cyanobacteria released enough O_2 to open the door to oxidation reactions in metabolic pathways. Aerobic prokaryotes were able to harvest more energy than anaerobic organisms and began to predominate. Increases in atmospheric O_2 levels also supported the evolution of large eukaryotic cells. Review Figure 25.8

25.3 What Are the Major Events in Life's History? • Paleontologists use the fossil record and evidence of geological changes to determine what Earth and its biota may have looked like at different times. Review Figure 25.12 • During most of its history, life was confined to the oceans. Multicellular life diversified extensively during the Cambrian explosion. Review Figure 25.13 • The remaining periods of the Paleozoic era were each characterized by the diversification of specific groups of organisms. The Paleozoic ended with the most drastic mass extinction in Earth's history, at the end of the Permian. Review Figure 25.14 • During the Mesozoic era, distinct terrestrial biotas evolved on each continent. Dinosaurs diversified to become the dominant large predators and herbivores. The era ended with a mass extinction event caused by the collision of a giant meteorite with Earth. • The Cenozoic era is divided into the Tertiary and the Quaternary periods, which in turn are subdivided into epochs. This era saw the emergence of the modern biota as mammals radiated extensively and the angiosperms

(flowering plants) became dominant. Review Table 25.2 See ACTIVITY 25.1 for a concept review of this chapter

PART SEVEN, THE EVOLUTION OF DIVERSITY

CHAPTER 26 Bacteria, Archaea, and Viruses

26.1 Where Do Prokaryotes Fit into The Tree of Life? • Two of life's three domains, Bacteria and Archaea, are prokaryotic. They are distinguished from Eukarya in several ways, including their lack of a nucleus and of membrane-enclosed organelles. Review Table 26.1 • Eukaryotes are related to both Archaea and Bacteria and appear to have originated through endosymbiosis between members of these two lineages. The last common ancestor of all three domains probably lived about 3 billion years ago. Review Figure 26.1, ANIMATED TUTORIAL 26.1 • Bacteria can be classified into two groups by the Gram stain. Gram-negative bacteria have a periplasmic space between the plasma membrane and a distinct outer membrane. Gram-positive bacteria have a thick cell wall containing about five times as much peptidoglycan as a Gram-negative wall. Review Figure 26.2, ACTIVITY 26.1 • The three most common bacterial shapes are cocci (spheres), bacilli (rods), and spirilla (helices). Review Figure 26.3 • Phylogenetic classification of prokaryotes is now based principally on the nucleotide sequences of rRNA and other genes involved in fundamental cellular processes. • Although lateral gene transfer has occurred throughout prokaryotic evolutionary history, elucidation of many aspects of prokaryote phylogeny is still possible. Review Figure 26.4

26.2 Why Are Prokaryotes So Diverse and Abundant? • Prokaryotes are the most numerous organisms on Earth. • The low-GC Gram-positives include the mycoplasmas, which are among the smallest cellular organisms ever discovered. • Some high-GC Gram-positives produce important antibiotics. • The photosynthetic cyanobacteria release oxygen into the atmosphere. Cyanobacteria may live free as single cells or associate in multicellular colonies. Review Figure 26.9 • Spirochetes have unique structures called axial filaments that allow them to move in a corkscrew-like manner. Review Figure 26.10 • The proteobacteria embrace the largest number of known species of bacteria. Smaller groups include the hyper thermophilic bacteria, hadobacteria, and chlamydias. • Many archaea are extremophiles. Review Figure 26.14 • Ether linkages in the branched long hydrocarbon chains of the lipids that make up the cell membranes are a synapomorphy of Archaea. Review Figure 26.15

26.3 How Do Prokaryotes Affect Their Environments? • Prokaryotes form complex communities, of which biofilms are one example. Review Figure 26.19 • Prokaryote metabolism is very diverse. Some prokaryotes are anaerobic, others are aerobic, and still others can shift between these modes. • Prokaryotes fall into four broad nutritional categories: photoautotrophs, photoheterotrophs, chemoautotrophs, and chemoheterotrophs. Review Table 26.2 • Prokaryotes play key roles in the cycling of elements such as nitrogen, oxygen, sulfur, and carbon. • Diverse communities of bacteria and archaea live on and in most animals. The composition of these microbiomes is often closely associated with the animal's health. Review Figure 26.21 • Koch's postulates establish the criteria by which an organism may be classified as a pathogen. Relatively few bacteria—and no archaea—are known to be pathogens. Review Figure 26.22

26.4 How Do Viruses Relate to Life's Diversity and Ecology? • Viruses have evolved many times from many different groups of cellular organisms. They are placed in groups according to the structure of their genomes, but these groups are not thought to represent monophyletic taxa. Review Figure 26.23 • Some viruses are probably derived from escaped components of cellular organisms; others are thought to have evolved as highly reduced parasites. Review Figure 26.25 • A large fraction of vertebrate (including human) genomes consists of incorporated remains of retroviral genomes. • Bacteriophages have been used to treat bacterial infections in humans. • Viruses are found in virtually all of Earth's environments and have a huge impact on the planet's ecosystems

CHAPTER 27 The Origin and Diversification of Eukaryotes

27.1 How Did the Eukaryotic Cell Arise? • The term protist does not describe a formal taxonomic group. It is shorthand for "all eukaryotes that are not plants, animals, or fungi." • Early events in the evolution of the eukaryotic cell probably included the loss of the firm cell wall and infolding of the plasma membrane. Such infolding probably led to segregation of the genetic material in a membrane-enclosed nucleus. Review Figure 27.1 • Mitochondria evolved by endosymbiosis with a proteobacterium. • Primary endosymbiosis of a eukaryote and a cyanobacterium gave rise to the first chloroplasts. Secondary endosymbiosis and tertiary endosymbiosis between chloroplast-containing eukaryotes and other eukaryotes gave rise to the distinctive chloroplasts of euglenids, dinoflagellates, and other groups. Review Figure 27.2, ANIMATED TUTORIAL 27.1

27.2 What Features Account for Protist Diversity? • Most eukaryotes can be placed in one of eight major clades that diverged about 1.5 billion years ago: alveolates, stramenopiles, rhizaria, excavates, plants, amoebozoans, fungi, and animals. Review Figure 27.3 • Most, but not all, protists are unicellular. • Alveolates are unicellular organisms with sacs (alveoli) beneath their plasma membranes. Alveolate clades include the marine dinoflagellates, the parasitic apicomplexans, and the diverse, highly motile ciliates. See ACTIVITY 27.1, ANIMATED TUTORIAL 27.2 • Stramenopiles typically have two flagella of unequal length, the longer one bearing rows of tubular hairs. Among the stramenopiles are the unicellular diatoms, the multicellular brown algae, and the non-photosynthetic oomycetes, many of which are saprobic. • Rhizaria are unicellular and aquatic. They include the cercozoans; the foraminiferans, which secrete shells of calcium carbonate; and the radiolarians, which have thin, stiff pseudopods and glassy endoskeletons. • The excavates include parasitic as well as free-living species. The diplomonads and parabasalids lack typical mitochondria. Heteroloboseans have an amoeboid body form and a two-stage life cycle. Euglenids have anterior flagella; some are photosynthetic. The kinetoplastids, which include several human pathogens, have a single, large mitochondrion. • The amoebozoans move by means of lobe-shaped pseudopods. A lobosean consists of a single amoeboid cell. Plasmodial slime molds are amoebozoans whose vegetative stage is a coenocyte that moves by cytoplasmic streaming. In cellular slime molds, the individual cells maintain their identity at all times but aggregate to form fruiting structures.

27.3 What is the Relationship between Sex and Reproduction in Protists? • Asexual reproduction gives rise to clonal lineages of organisms. • Conjugation in Paramecium is a sexual process but not a reproductive one. Review Figure 27.19 • Alternation of generations, which includes a multicellular diploid stage and a multicellular haploid stage, is a feature of many multicellular protist life cycles (as

well as those of some fungi and all land plants). The alternating generations may be heteromorphic or isomorphic.

27.4 How Do Protists Affect Their Environments? • The diatoms are responsible for about one-fifth of the photosynthetic carbon fixation on Earth. They and other members of the phytoplankton are important primary producers in the marine environment. Ancient diatoms are a major source of today's petroleum and natural gas deposits. • Some protists are pathogens of humans and other vertebrates. Review Figure 27.20, ANIMATED TUTORIAL 27.3 • Endosymbiotic relationships are common among microbial protists and typically benefit both the endosymbionts and their protist or animal partners. Review Figure 27.2

CHAPTER 28 Plants without Seeds: From Water to Land

28.1 How Did Photosynthesis Arise in Plants? • Primary endosymbiosis gave rise to chloroplasts and the subsequent diversification of the Plantae. The descendants of the first photosynthetic eukaryote include glaucophytes, red algae, several groups of green algae, and land plants, all of which contain chlorophyll a. Review Figure 28.1 • Green plants, which include the green algae and the land plants, are characterized by the presence of chlorophyll b (in addition to chlorophyll a). Review Figure 28.1 • Land plants, also known as embryophytes, arose from an aquatic green algal ancestor related to today's stoneworts. Land plants develop from embryos that are protected by parental tissue. Review Figure 28.1

28.2 When and How Did Plants Colonize Land? • The acquisition of a cuticle, stomata, gametangia, a protected embryo, protective pigments, thick spore walls with a protective polymer, and mutualistic associations with fungi were all adaptations of land plants to terrestrial life. • All land plant life cycles feature alternation of generations, in which a multicellular diploid sporophyte alternates with a multicellular haploid gametophyte. Review Figure 28.6 • The nonvascular land plants comprise the liverworts, mosses, and hornworts. These groups lack specialized vascular tissues for the conduction of water or nutrients through the plant body. • The life cycles of nonvascular land plants depend on liquid water. The sporophyte is usually smaller than the gametophyte and depends on it for water and nutrition. Review Figure 28.7, ANIMATED TUTORIAL 28.1 • Liverworts lack stomata, but they are present in mosses, hornworts, and vascular plants. Hornworts have a persistently green sporophyte, a characteristic shared with vascular plants.

28.3 What Features Allowed Land Plants to Diversify in Form? • The vascular plants have a vascular system consisting of xylem and phloem that conducts water, minerals, and products of photosynthesis through the plant body. The vascular system includes cells called tracheids. • The rhyniophytes, the earliest known vascular plants, are known to us only in fossil form. They lacked true roots and leaves but possessed rhizomes and rhizoids. Review Figure 28.13 • The lycophytes (club mosses and relatives) have only small, simple leaflike structures (microphylls). Monilophytes (which include horsetails and ferns) have true leaves, and so together with seed plants are known as euphyllophytes. • Unlike nonvascular land plants, the diploid sporophyte is the more conspicuous life stage of lycophytes and monilophytes. Review Figure 28.15, ACTIVITY 28.1 • Microphylls probably evolved from sterile sporangia. Megaphylls (true leaves) may have resulted from the flattening and reduction of a portion of a stem system with overtopping growth. Review Figure 28.16 • The earliest-diverging groups of vascular plants are homosporous, but heterospory—the production of distinct megaspores and microspores—has evolved

several times. Megaspores develop into female megagametophytes; microspores develop into male microgametophytes. Review Figure 28.18, ACTIVITIES 28.2 and 28.3

CHAPTER 29 The Evolution of Seed Plants

29.1 How Did Seed Plants Become Today's Dominant Vegetation? • Fossils of woody seed ferns are the earliest evidence of seed plants. The surviving groups of seed plants are the gymnosperms and angiosperms. Review Figure 29.1 • All seed plants are heterosporous, and their gametophytes are much smaller than (and dependent on) their sporophytes. Review Figure 29.2 • Seed plants do not require liquid water for fertilization. Pollen grains, the microgametophytes of seed plants, are carried to a megagametophyte by wind or by animals. • An ovule consists of the seed plant megagametophyte and the integument of sporophytic tissue that protects it. • Following pollination, a pollen tube emerges from the pollen grain, elongates, and usually delivers gametes to the megagametophyte. Review Figure 29.4, ACTIVITY 29.1 • The ovule develops into a seed that contains an embryo (the new sporophyte generation). Seeds are well protected and are often capable of long periods of dormancy, germinating only when conditions are favorable. Review Figure 29.5

29.2 What Are the Major Groups of Gymnosperms? • The gymnosperms produce ovules and seeds that are not protected by ovary or fruit tissues. • The major gymnosperm groups are the cycads, ginkgos, gnetophytes, and conifers. Review Figure 29.6 • The megaspores of conifers are produced in woody cones called megastrobili; the microspores are produced in herbaceous cones called microstrobili. Review Figures 29.7 and 29.8, ACTIVITY 29.2, ANIMATED TUTORIAL 29.1

29.3 How Do Flowers and Fruits Increase the Reproductive Success of Angiosperms? • Flowers and fruits are unique to the angiosperms, distinguishing them from the gymnosperms. • The xylem of most angiosperms is more complex than that of the gymnosperms. It contains two specialized cell types: vessel elements, which function in water transport, and fibers, which play an important role in structural support. • The ovules and seeds of angiosperms are enclosed in and protected by carpels. • The floral organs, from the base to the apex of the flower, are the sepals, petals, stamens, and pistil. Stamens bear microsporangia in anthers. The pistil (consisting of one or more carpels) includes an ovary containing ovules. The stigma is the receptive surface of the pistil. • A flower with both megasporangia and microsporangia is referred to as perfect; a flower with only one or the other is imperfect. • A monoecious species has megasporangiate and microsporangiate flowers on the same plant. A dioecious species is one in which megasporangiate and microsporangiate flowers occur on different plants. • The carpels and stamens of flowers probably evolved from leaflike structures. Review Figure 29.12 • Some plants with perfect flowers have adaptations to prevent self-fertilization. Review Figure 29.13 • Many angiosperms have coevolved with their animal pollinators. • Angiosperms exhibit double fertilization, usually resulting in the production of a diploid zygote and triploid endosperm. Review Figure 29.16, ANIMATED TUTORIAL 29.2 • The oldest evolutionary split among the angiosperms is between the clade represented by the single species in the genus Amborella and all the remaining flowering plants. Review Figure 29.18 • The most species-rich angiosperm clades are the monocots and the eudicots. The magnoliids are likely the sister group to the monocots and eudicots.

29.4 How Do Plants Benefi t Human Society? • Plants provide ecosystem services that affect soil, water, air quality, and climate. • Plants are primary producers and as such are the foundation of terrestrial food webs. • Plants provide humans with many important medicinal products.

CHAPTER 30 The Evolution and Diversity of Fungi

30.1 What Is a Fungus? • Fungi are distinguished from other opisthokonts by absorptive heterotrophy and by the presence of chitin in their cell walls. Review Figure 30.1 • Some fungi are saprobes, others are parasites, and some are mutualists. • Yeasts are unicellular, free-living fungi. • The body of a multicellular fungus is a mycelium—a meshwork of filaments called hyphae. Hyphae may be septate (having septa) or coenocytic (multinucleate). Review Figure 30.3

30.2 How Do Fungi Interact with Other Organisms? • Saprobic fungi, which act as decomposers, make crucial contributions to the recycling of elements, especially carbon. • Many fungi are parasites, harvesting nutrients from host cells by means of haustoria. Review Figure 30.5 • Certain fungi have relationships with other organisms that are symbiotic and mutualistic. • Some fungi associate with unicellular green algae, cyanobacteria, or both to form lichens, which live on exposed surfaces of rocks, trees, and soil. Review Figure 30.8 • Mycorrhizae are mutualistic associations of fungi with plant roots. They improve a plant's ability to take up nutrients and water. • Endophytic fungi live within plants and may provide their hosts with protection from herbivores and pathogens.

30.3 How Do Major Groups of Fungi Differ in Structure and Life History? • The microsporidia, chytrids, and zygospore fungi diversified early in fungal evolution. The arbuscular mycorrhizal fungi, sac fungi, and club fungi form a monophyletic group, and the latter two groups form the clade Dikarya. Review Figure 30.10, Table 30.1, ACTIVITY 30.1 • Many species of fungi reproduce both sexually and asexually. In many fungi, sexual reproduction occurs between individuals of different mating types. Review Figure 30.11 • The microsporidia are highly reduced unicellular fungi. They are obligate intracellular parasites of animals. • The three distinct lineages of chytrids all include species with flagellated gametes. Review Figure 30.14A • In the sexual reproduction of terrestrial fungi, plasmogamy (fusion of cytoplasm) precedes karyogamy (fusion of nuclei). • Zygospore fungi have a resting stage known as a zygospore, which contains many diploid nuclei. Their spores are dispersed from simple stalked sporangiophores. Review Figure 30.14B, ANIMATED TUTORIAL 30.1 • Arbuscular mycorrhizal fungi form symbiotic associations with plant roots. They are only known to reproduce asexually. Their hyphae are coenocytic. • In sac fungi and club fungi, a mycelium containing two genetically different haploid nuclei, called a dikaryon, is formed. The dikaryotic (n + n) condition is unique to the fungi. Review Figure 30.16, ACTIVITY 30.2 • Sac fungi have septate hyphae with large pores; their sexual reproductive structures are asci. Some sac fungi are unicellular yeasts. Many filamentous sac fungi produce fleshy fruiting structures called ascomata. The dikaryon stage in the sac fungus life cycle is relatively brief. Review Figure 30.16A • Club fungi have septate hyphae with distinctive small pores. Their fruiting structures are called basidiomata, and their sexual reproductive structures are basidia. The dikaryon stage may last for years. Review Figure 30.16B

30.4 What Are Some Applications of Fungal Biology? • Some fungi are consumed as food by humans; other fungi are critical in baking, fermentation, and flavoring food. • Fungi play important roles in cleaning up environmental pollutants such as synthetic petroleum-derived hydrocarbons

• The diversity and abundance of lichen growth on trees is a sensitive indicator of air quality. • Reforestation projects require restoration of the mycorrhizal fungal community. • Several species of fungi are important model organisms. • Fungi provide important weapons against diseases and pests.

CHAPTER 31 Animal Origins and the Evolution of Body Plans

31.1 What Characteristics Distinguish the Animals? • Animals share a set of derived traits not found in other groups of organisms. These traits include similarities in the sequences of many of their genes, the structure of their cell junctions, and the components of their extracellular matrix. • Patterns of embryonic development provide clues to the evolutionary relationships among animals. Diploblastic animals, which include the ctenophores, placozoans, and cnidarians, develop two embryonic cell layers. Triploblastic animals develop three cell layers. Review Figure 31.1 • Differences in their patterns of early development characterize two major triploblastic clades, the protostomes and the deuterostomes.

31.2 What Are the Features of Animal Body Plans? • Animal body plans can be described in terms of symmetry, body cavity structure, segmentation, types of appendages, and nervous system development. • A few animals have no symmetry, but most animals have either radial symmetry or bilateral symmetry. Review Figure 31.4 • Many bilaterally symmetrical animals exhibit cephalization: the concentration of sensory organs and nervous tissues in an anterior head. • On the basis of their body cavity structure, animals can be described as acoelomates, pseudocoelomates, or coelomates. Review Figure 31.5, ACTIVITY 31.1 • Segmentation, which takes many forms, improves control of movement, as do appendages. Review Figure 31.6 • The development of a nervous system is important for the coordination of muscular movement and the processing of sensory information. How Do Animals Get Their Food? • Motile animals can move to find food; sessile animals stay in one place, but may expend energy to move the environment and the food it contains to them • Filter feeders strain small organisms and organic molecules from their environment. • Herbivores consume plants, usually without killing them. • Predators have morphological features such as sharp teeth, beaks, and claws that enable them to capture and subdue animal prey. • Parasites live in or on other organisms and obtain nutrition from those host individuals. • Detritivores consume dead organic matter and return the nutrients it contains to the ecosystem.

31.4 How Do Life Cycles Differ among Animals? • The stages of an animal's life cycle may be specialized for different activities. An immature stage whose morphology is dramatically different from that of the adult stage is called a larva. • Most animal life cycles have at least one dispersal stage. Many sessile marine animals can be grouped by the presence of one of two distinct larval dispersal stages: trochophore or nauplius. Review Figure 31.10 • A characteristic of an animal or a life cycle stage may improve the animal's performance in one activity but reduce its performance in another, a situation known as a trade-off. • Parasites have complex life cycles that may involve one or more hosts and several larval stages. Review Figure 31.11 • In some groups of animals, asexual reproduction without fission leads to the formation of colonies composed of many genetically homogeneous, physiologically integrated individuals.

31.5 What Are the Major Groups of Animals? • Eumetazoans include all animals except sponges. Animals other than sponges, ctenophores, placozoans, and cnidarians—that is, the triploblastic protostomes and deuterostomes—belong to a large monophyletic group called bilaterians. Review

Figure 31.1, ACTIVITY 31.2 • Sponges are simple animals that lack differentiated cell layers and true organs. They have skeletons made up of silicaceous or calcareous spicules. They create water currents and capture food with flagellated feeding cells called choanocytes. Review Figure 31.2 • Ctenophores are radially symmetrical and have two cell layers separated by an inert extracellular matrix called mesoglea. Review Figure 31.16 • Placozoans are asymmetrical as adults. They have only a few cell types and lack true organs, although their simplicity may be secondarily derived. • The life cycle of most cnidarians has two distinct stages: a sessile polyp stage and a motile medusa stage that reproduces sexually. A fertilized egg develops into a free-swimming planula larva, which settles to the bottom and develops into a polyp. Review Figures 31.18, 31.22, ANIMATED TUTORIAL 31.1

CHAPTER 32 Protostome Animals

32.1 What Is a Protostome? • Protostomes ("mouth first") are bilaterally symmetrical animals with an anterior brain that surrounds the entrance to the digestive tract and a ventral nervous system. The embryonic blastopore of protostomes develops into a mouth. • There are two major clades of protostomes, the lophotrochozoans and the ecdysozoans. Review Figure 32.1, Table 32.1, ACTIVITIES 32.1, 32.2, ANIMATED TUTORIAL 32.1 • Lophotrochozoans include a wide variety of body forms. Within this group, lophophores (complex organs for both food collection and gas exchange), free-living trochophore larvae, and spiral cleavage evolved. Some of these features were subsequently lost in some lineages (or evolved convergently). • Ecdysozoans have a body covering known as the cuticle, which they must molt in order to grow. Some ecdysozoans have a relatively thin cuticle. Others, especially the arthropods, have a rigid cuticle reinforced with chitin that functions as an exoskeleton. Review Figure 32.4 • Arrow worms may be most closely related to lophotrochozoans, or they may be the sister group of all other protostomes. Review Figure 32.5

32.2 What Features Distinguish the Major Groups of Lophotrochozoans? • Lophotrochozoans range from animals with a blind gut and no internal transport system to animals with complete digestive tracts and complex internal transport systems. Review Figure 32.6 • Most species of bryozoans and entoprocts live in colonies produced through asexual reproduction. Individuals of both groups feed using a lophophore. • Flatworms, rotifers, gastrotrichs, and their close relatives form a structurally diverse clade of ciliated lophotrochozoans. Review Figure 32.7 • Ribbon worms feed using a long, protrusible proboscis. Review Figure 32.8

• The shelled brachiopods and wormlike phoronids use a lophophore to feed; this lophophore may have evolved independently of the lophophore in bryozoans and entoprocts. Review Figures 32.9, 32.10 • Annelids are a diverse group of segmented worms that live in moist terrestrial and aquatic environments. Review Figure 32.11 • Mollusks underwent a dramatic evolutionary radiation based on a body plan consisting of three major components: a foot, a mantle, and a visceral mass. The four major living molluscan clades—chitons, bivalves, gastropods, and cephalopods— demonstrate the diversity that evolved from this three-part body plan. Review Figure 32.13

32.3 What Features Distinguish the Major Groups of Ecdysozoans? • Members of several species-poor groups of wormlike marine ecdysozoans—priapulids, kinorhynchs, and loriciferans—have thin cuticles. • Nematodes have a thick, multilayered cuticle. Nematodes are among the most abundant and universally

distributed of all animal groups. Review Figure 32.16 • Horsehair worms are extremely thin; many are endoparasites as larvae.

32.4 Why Are Arthropods So Diverse? • One major ecdysozoan clade, the arthropods, has evolved jointed, paired appendages that have a wide diversity of functions. Collectively, arthropods are the dominant animals on Earth in number of described species, and among the most abundant in number of individuals. • Encasement within a rigid exoskeleton provides arthropods with support for walking as well as some protection from predators. The waterproofing provided by chitin keeps arthropods from dehydrating in dry air. • Jointed appendages permit complex movement patterns. Each arthropod segment has muscles attached to the inside of the exoskeleton that operate that segment and the appendages attached to it. • The onychophorans and the tardigrades are arthropod relatives that have simple, unjointed appendages. Trilobites, the first arthropods known to have had jointed appendages, disappeared in the Permian mass extinction. • Chelicerates have a two-part body and pointed mouthparts that grasp prey; most chelicerates have four pairs of walking legs. • Mandibles and antennae are synapomorphies of the mandibulates, which include the myriapods, crustaceans, and hexapods. • The bodies of myriapods have two regions: a head with mandibles and antennae, and a segmented trunk that bears many pairs of legs. • Crustaceans have segmented bodies that are divided into three regions—head, thorax, and abdomen—with different, specialized appendages in each region. Review Figure 32.24 • Hexapods—insects and their relatives—are the dominant terrestrial arthropods. They have the same three body regions as crustaceans, but no appendages form in their abdominal segments. Review Figure 32.26, Table 32.2 • Wings and the ability to fly first evolved among the pterygote insects, allowing them to exploit new lifestyles. Review Figure 32.28

CHAPTER 33 Deuterostome Animals

33.1 What Is a Deuterostome? • Deuterostomes vary greatly in adult form, but based on the distinctive patterns of early development they share and on phylogenetic analyses of their gene sequences, they are judged to be monophyletic. • There are far fewer species of deuterostomes than of protostomes, but many deuterostomes are large and ecologically important. • The deuterostomes comprise three major clades: the echinoderms, hemichordates, and chordates. Review Figure 33.1, ACTIVITY 33.1, ANIMATED TUTORIAL 33.1

33.2 What Features Distinguish the Echinoderms, Hemichordates, and Their Relatives? • Echinoderms and hemichordates, together called ambulacrarians, have bilaterally symmetrical, ciliated larvae. Adult echinoderms have pentaradial symmetry and an oral–aboral body orientation. Review Figure 33.3 • The xenoturbellids and acoels are reduced, soft-bodied wormlike marine animals with few distinct organ systems. Their relationships are uncertain, but recent analyses suggest that they may be the sister group of the ambulacrarians. • Echinoderms have an internal skeleton of calcified plates and a unique water vascular system connected to extensions called tube feet. Review Figure 33.3 • Hemichordates are bilaterally symmetrical and have a three-part body divided into a proboscis, collar, and trunk. Review Figure 33.6

33.3 What New Features Evolved in the Chordates? • Chordates fall into three principal clades: lancelets, tunicates, and vertebrates. • At some stage in their development, all chordates have a dorsal hollow nerve cord, a post-anal tail, and a notochord. Lancelets have all three key chordate features as

adults. Tunicates have these features as larvae but lose them as adults. Review Figure 33.7 • The vertebrate body is characterized by an internal skeleton, which is supported by a vertebral column that replaces the notochord. It is also characterized by internal organs suspended in a coelom, a ventral heart, and an anterior skull enclosing a large brain. Review Figure 33.9 • From estuarine ancestors, vertebrates diversified into many lineages of marine and freshwater fishes. One of these lineages, the lobe-limbed vertebrates, later radiated into terrestrial environments. Review Figure 33.10 • In the gnathostomes, jaws evolved from gill arches. Jaws enabled these vertebrates to grasp large prey and, together with teeth, allowed them to cut food into small pieces. Review Figure 33.12 • Chondrichthyans have skeletons of cartilage; almost all species are marine. The skeletons of ray-finned fishes are made of bone; these fishes have colonized all aquatic environments.

33.4 How Did Vertebrates Colonize the Land? • Lungs and jointed appendages enabled one lineage of lobe limbed vertebrates to colonize the land. This lineage gave rise to the tetrapods. Review Figure 33.16 • The earliest split in the tetrapod tree is between the amphibians and the amniotes (reptiles and mammals). • Most modern amphibians are confined to moist environments because their bodies and their eggs lose water rapidly. Review Figure 33.17, ANIMATED TUTORIAL 33.2 • An impermeable skin, efficient kidneys, and an amniote egg that could resist desiccation evolved in the amniotes. Review Figure 33.19, ACTIVITY 33.2 • The major living reptile groups are the lepidosaurs (tuataras, along with the squamates, which include lizards, snakes, and amphisbaenians), the turtles, and the archosaurs (crocodilians and birds). Review Figure 33.20 • Birds evolved from a group of active, predatory dinosaurs known as theropods. Feathers arose among the theropods, originally for insulation and to enhance coloration, but eventually developed into adaptations for flight in birds. Review Figures 33.23, 33.24 • Mammals are unique among animals in supplying their young with a nutritive fluid (milk) secreted by mammary glands. There are two primary mammalian clades: the prototherians (of which there are only five species) and the species-rich therians. The therian clade is further subdivided into the marsupials and the eutherians. Review Table 33.1 • Mammalian phylogeny is strongly associated with the breakup of the major continents during the Mesozoic. Major lineages of eutherians diversified in Laurasia, Africa, and South America. Review Figure 33.28

33.5 What Traits Characterize the Primates? • Grasping limbs with opposable digits distinguish primates from other mammals. The prosimian clade includes the lemurs, lorises, and galagos; the anthropoid clade includes tarsiers, monkeys, and apes. Review Figure 33.30 • The ancestors of hominins were terrestrial apes that developed efficient bipedal locomotion. Review Figure 33.34 • In the lineage leading to Homo, brains became larger as jaws became smaller; the two events appear to be developmentally linked and are an example of evolution via neoteny. Review Figure 33.35 See ACTIVITY 33.3 for a concept review of this chapter

PART EIGHT, FLOWERING PLANTS: FORM AND FUNCTION

CHAPTER 34 The Plant Body

34.1 What Is the Basic Body Plan of Plants? • The vegetative organs of flowering plants are roots, which form a root system, and stems and leaves, which form a shoot system. Review Figure 34.1 • Plant

development differs from animal development in that plants have apical meristems, cell walls, vacuoles, and in some cases, totipotent cells. • Plants have apical–basal and radial axes of symmetry. Review Figures 34.3, 34.4

34.2 What Are the Major Tissues of Plants? • Three tissue systems, arranged concentrically, extend throughout the plant body: the vascular tissue, dermal tissue, and ground tissue systems. Review Figure 34.5 • The dermal tissue system protects the plant body surface. Dermal cells form the epidermis and, in woody plants, the periderm. • The ground tissue system contains cells of three types. Some parenchyma cells carry out photosynthesis; others store starch. Collenchyma cells provide flexible support. Sclerenchyma cells include fibers and sclereids that provide strength and mechanical support. Review Figures 34.6, 34.7 • The vascular tissue system includes xylem, which conducts water and minerals absorbed by the roots, and phloem, which conducts the products of photosynthesis throughout the plant body. • Tracheary elements include tracheids and vessel elements, which are the conducting cells of the xylem. Sieve tube elements are the conducting cells of the phloem.

34.3 How Do Meristems Build a Continuously Growing Plant? • All seed plants possess a primary plant body consisting of nonwoody tissues. Woody plants also possess a secondary plant body consisting of wood and bark. Apical meristems generate the primary plant body, and lateral meristems generate the secondary plant body. Review Figure 34.8 • Apical meristems are responsible for primary growth (lengthening of roots and shoots). Apical meristems at the tips of stems and roots give rise to three primary meristems (protoderm, ground meristem, and procambium), which in turn produce the three tissue systems of the primary plant body. • The root apical meristem gives rise to the root cap and to three primary meristems. Root tips have overlapping zones of cell division, cell elongation, and cell maturation. Review Figure 34.9

• The vascular tissue of roots is contained within the stele. It is arranged differently in eudicot and monocot roots. Review Figures 34.10, 34.11, ACTIVITIES 34.1, 34.2 • In nonwoody stems, the vascular tissue is divided into vascular bundles, each containing both xylem and phloem. Review Figure 34.13, ACTIVITIES 34.3, 34.4 • Eudicot leaves have two zones of photosynthetic mesophyll that are supplied by veins with water and minerals. Veins also carry the products of photosynthesis to other parts of the plant body. A waxy cuticle limits water loss from the leaf. Guard cells control openings called stomata in the leaf that allow CO_2 to enter, but also allow some water to escape. Review Figure 34.15, ACTIVITY 34.5 • Two lateral meristems, the vascular cambium and cork cambium, are responsible for secondary growth. The vascular cambium produces secondary xylem (wood) and secondary phloem. The cork cambium produces a protective tissue called cork. Review Figures 34.16, 34.17, ANIMATED TUTORAL 34.1

34.4 How Has Domestication Altered Plant Form? • The plant body plan is simple, yet it can be changed dramatically by minor differences in genes, as evidenced by the natural diversity of wild plants. • Crop domestication involves artificial selection of certain desirable traits found in wild populations. Review Figure 34.20

CHAPTER 35 Transport in Plants

35.1 How Do Plants Take Up Water and Solutes? • Water moves through biological membranes by osmosis, always moving toward regions with a more negative water potential. The water potential (Ψ) of a cell or solution is the sum of the solute potential (Ψs) and the pressure potential (Ψp). Review Figure 35.2, ANIMATED TUTORIAL 35.1 • Turgid plant cells have significant positive pressure potential because the rigid cell wall limits expansion of the cell. This positive pressure (turgor pressure) maintains the physical structure of many plant cells; if the pressure potential drops, the plant wilts. • The movement of a solution due to a difference in pressure potential between two parts of a plant is called bulk flow. • Aquaporins are channel proteins that facilitate movement of water molecules through biological membranes. • Mineral uptake requires transport proteins. Some minerals enter the plant passively by facilitated diffusion; others enter by active transport. A proton pump provides energy for the active transport of many mineral ions across membranes in plants. Review Figure 35.4 • Water and minerals pass from the soil into the root by way of the apoplast and symplast, but must pass through the symplast to cross the endodermis and enter the xylem. The Casparian strip in the endodermis blocks movement of water and minerals through the apoplast. Review Figures 35.5, 35.6, ACTIVITY 35.1

35.2 How Are Water and Minerals Transported in the Xylem? • Experiments proved that neither a root pump nor capillary action can alone account for the ascent of xylem sap in trees. • Water transport in the xylem results from the combined effects of transpiration, cohesion, and tension—the transpiration–cohesion–tension mechanism. Evaporation from the leaf produces tension in the mesophyll cells, which pulls a column of water— held together by cohesion—up through the xylem from the root. Review Figure 35.7, ANIMATED TUTORIAL 35.2 • Transport in the xylem is passive. It does not require the expenditure of energy by the plant.

35.3 How Do Stomata Control the Loss of Water and the Uptake of CO2? • The waxy cuticle of plant epidermis is impermeable to both water and carbon dioxide. Stomata allow for carbon dioxide uptake (when open) while minimizing transpirational water loss (when closed). • A pair of guard cells controls the size of the stomatal opening. A light-activated proton pump moves protons out of the guard cells to the walls of surrounding epidermal cells, setting up an electrochemical gradient that drives the transport of potassium ions into the guard cells. Water follows osmotically, swelling the guard cells and opening the stomata. Review Figure 35.9 • When threatened by dehydration, mesophyll cells release abscisic acid, which causes guard cells to close the stomata, even in the light.

35.4 How Are Substances Translocated in the Phloem? • Products of photosynthesis, as well as some minerals, are translocated through sieve tubes in the phloem by way of living sieve tube elements. Review Figure 35.10 • Translocation in the phloem can proceed in both directions in the stem. Translocation requires a supply of ATP. • Translocation in the phloem is explained by the pressure flow model: the difference in solute concentration between sources and sinks creates a difference in (positive) pressure potential along the sieve tubes, resulting in bulk flow. Review Figure 35.11, Table 35.1, ANIMATED TUTORIAL 35.3

CHAPTER 36 Plant Nutrition

36.1 What Nutrients Do Plants Require? • Plants are photosynthetic autotrophs that can produce all their organic molecules from carbon dioxide, water, and minerals, including a nitrogen source. • Mineral nutrients are obtained from the soil solution. • Plants require 14 essential elements, 6 of which are

macronutrients and 8 of which are micronutrients. Deficiency symptoms suggest what essential element a plant lacks. Review Table 36.1, Figure 36.1, ANIMATED TUTORIAL 36.1 • The essential elements were discovered by growing plants hydroponically, meaning in solutions that lacked individual elements. Review Figure 36.2

36.2 How Do Plants Acquire Nutrients? • Root growth allows plants, which are sessile, to search for mineral resources. • Plants can regulate the uptake of nutrients by increasing the number or activity of active transport proteins in root epidermal cells. Review Figure 36.3

36.3 How Does Soil Structure Affect Plants? • Soils contain water, air, and inorganic and organic substances. Soils have living (biotic) and nonliving (abiotic) components. Review Figure 36.4 • A soil typically consists of two or three horizontal zones called horizons. Topsoil forms the uppermost or A horizon. Topsoil tends to lose mineral nutrients through leaching. Loams are excellent agricultural topsoils, with a good balance of sand, silt, clay, and organic matter. Review Figure 36.5 • Soils form by mechanical and chemical weathering of rock. Chemical weathering imparts mineral nutrients to clay particles. Plant litter and other organic matter decompose to form humus. Plants obtain some mineral nutrients through cation exchange between the soil solution and the surface of clay particles. Review Figure 36.6 • Farmers use fertilizers to make up for deficiencies in soil mineral nutrient content.

36.4 How Do Fungi and Bacteria Increase Nutrient Uptake by Plant Roots? • Mycorrhizae are symbiotic root–fungus associations that greatly increase a plant's absorption of water and minerals, especially phosphorus. They occur in more than 90 percent of terrestrial plant species. • The arbuscules are the sites of nutrient exchange between the fungus and plant. Review Figure 36.7 • In the earliest stages of mycorrhiza formation, the hyphae of arbuscular fungi grow toward strigolactones, compounds that are produced by the plant roots. • Some nitrogen fixers live free in soil or water; others live symbiotically as bacteroids within plant roots. The formation of a root nodule requires interaction between the root system of a legume and rhizobia. Review Figure 36.7 • Several steps in the formation of root nodules and arbuscules are similar and probably involve some of the same plant genes. Review Figure 36.8 • In nitrogen fixation, nitrogen gas (N_2) is reduced to ammonia (NH_3) or ammonium ions (NH_4^+) in a reaction catalyzed by nitrogenase. Review Figure 36.9 • Plants and bacteria interact in the global nitrogen cycle, which involves a series of reductions and oxidations of nitrogen-containing molecules. Review Figure 36.10, ACTIVITY 36.1

36.5 How Do Carnivorous and Parasitic Plants Obtain a Balanced Diet? • Carnivorous plants are autotrophs that supplement a low nitrogen supply by feeding on insects or other small animals. • Parasitic plants draw on other plants to meet their needs, which may include minerals, water, or the products of photosynthesis. • Hemiparasites, such as mistletoes, can still photosynthesize. Holoparasites cannot function as autotrophs because they have lost chloroplast genes that code for components of the photosynthetic apparatus (which they no longer need). • A strigolactone—a compound in the same category of compounds plants use to attract mycorrhizal fungi—also induces the germination of some parasitic plants, including Striga. Scientists hypothesize that a mechanism evolved in the ancestors of modern Striga to recognize a compound that was already produced by plants to attract arbuscular fungi

CHAPTER 37 Regulation of Plant Growth

37.1 How Does Plant Development Proceed? • As sessile organisms, plants maximize their ability to grow by using meristems, forming new organs, and growing throughout life. • The environment, photoreceptors, hormones, and the plant's genome all regulate plant development. • Seed dormancy, which has adaptive advantages, is maintained by a variety of mechanisms. In nature, dormancy is broken by, for example, abrasion, fire, leaching, and low temperatures. When dormancy ends and the seed imbibes water, it germinates and develops into a seedling. Review Figure 37.1, ACTIVITIES 37.1, 37.2 • Plant hormones differ in structure and physiology from animal hormones. Review Table 37.1 • Plants have several hormones, each of which regulates multiple aspects of development. Interactions among these hormones are often complex. Review Table 37.2 • Genetic screens using the model organism Arabidopsis thaliana have contributed greatly to our understanding of signaling in plants. Review Figure 37.2

37.2 What Do Gibberellins and Auxin Do? • Both gibberellins and auxin can induce growth in plants otherwise genetically destined to be dwarfs. Review Figure 37.3 • Gibberellins have many effects that vary among different plants, including cell elongation, fruit ripening, and mobilization of seed storage polymers. Review Figures 37.3–37.5, ACTIVITY 37.3 • Auxin was discovered in the context of stem and coleoptile growth, in particular phototropism. In the shoot, it is made in the growing tip and transported down to stimulate cell elongation. Review Figures 37.6, 37.7, ANIMATED TUTORIALS 37.1, 37.2 • According to the acid growth hypothesis, auxin stimulates cell elongation through the release of protons into the cell wall (acidification of the cell wall). Review Figure 37.10, ANIMATED TUTORIAL 37.3 • Both auxin and gibberellins act through the breakdown of transcriptional repressors.

37.3 What Are the Effects of Cytokinins, Ethylene, and Brassinosteroids? • Cytokinins are adenine derivatives that promote plant cell division, promote seed germination in some species, inhibit stem elongation, promote lateral swelling of stems and roots, stimulate the growth of axillary buds, promote the expansion of leaf tissue, and delay leaf senescence. • A balance between auxin and ethylene controls leaf abscission. Ethylene promotes senescence and fruit ripening. It indirectly causes the formation of a protective apical hook in eudicot seedlings. In stems, it inhibits elongation, promotes lateral swelling, and causes a loss of gravitropic sensitivity. • Ethylene acts on cells by a protein kinase pathway located in the endoplasmic reticulum. Review Figure 37.14 • Dozens of different brassinosteroids affect cell elongation, pollen tube elongation, vascular tissue differentiation, and root elongation. These steroids act at a plasma membrane receptor.

37.4 How Do Photoreceptors Participate in Plant Growth Regulation? • Phototropins are blue-light photoreceptors for phototropism and chloroplast movements. Zeaxanthin acts in conjunction with the phototropins to mediate the light-induced opening of stomata. Cryptochromes are blue-light photoreceptors that control seedling development, stem elongation, and floral initiation. • Phytochrome exists in the cytosol in two interconvertible forms, Pr and Pfr. The relative amounts of these two forms are a function of the ratio of red to far-red light. Phytochrome affects seedling growth, flowering, and etiolation. Review Figure 37.16 • The phytochrome signal transduction pathway affects transcription in two different ways; the Pfr form interacts directly with some transcription factors, and influences transcription indirectly through interactions with protein kinases. Review Figure 37.18 • Circadian rhythms are activities that occur on a near-24-hour cycle. Light can entrain these activities through photoreceptors such as phytochrome

CHAPTER 38 Reproduction in Flowering Plants

38.1 How Do Angiosperms Reproduce Sexually? • Sexual reproduction promotes genetic diversity in a population. The flower is an angiosperm's structure for sexual reproduction. • Flowering plants have microscopic gametophytes. The megagametophyte is the embryo sac, which typically contains eight nuclei in a total of seven cells. The microgametophyte is the pollen grain, which usually contains two cells. Review Figure 38.2, ACTIVITY 38.1 • Following pollination, the pollen grain delivers sperm cells to the embryo sac by means of a pollen tube. Review ANIMATED TUTORIAL 38.1 • Plants have both physical and genetic methods of preventing inbreeding. Physical separation of the gametophytes and genetic self-incompatibility prevent self-pollination. Review Figure 38.5 • Most angiosperms exhibit double fertilization: one sperm cell fertilizes the egg cell, forming a zygote, and the other sperm cell fertilizes the central cell, where its nucleus unites with the two polar nuclei to form a triploid endosperm. Review Figure 38.6 • Ovules develop into seeds, and the ovary wall and the enclosed seeds develop into a fruit. • The hormone abscisic acid promotes seed development and dormancy.

38.2 What Determines the Transition from the Vegetative to the Flowering State? • In annuals and biennials, flowering and seed formation usually leads to death of the rest of the plant. Perennials live a long time and typically reproduce repeatedly. • For a vegetatively growing plant to flower, an apical meristem in the shoot system must become an inflorescence meristem, which in turn must give rise to one or more floral meristems. These events are under the influence of meristem identity genes and floral organ identity genes. Review Figure 38.8

• Some plants flower in response to photoperiod. Short-day plants flower when the nights are longer than a critical night length specific to each species; long-day plants flower when the nights are shorter than a critical night length. Review Figure 38.11 • The mechanism of photoperiodic control involves phytochromes and a biological clock. Review Figure 38.12, ANIMATED TUTORIAL 38.2 • A flowering signal, called florigen, is formed in a photo periodically induced leaf and is translocated to the sites where flowers will form. Review Figures 38.13, 38.14 • In some angiosperm species, exposure to low temperatures— vernalization—is required for flowering; in others, internal signals (one of which is gibberellin in some plants) induce flowering. Review Figures 38.15, 38.16

38.3 How Do Angiosperms Reproduce Asexually? • Asexual reproduction allows rapid multiplication of organisms that are well suited to their environment. • Vegetative reproduction involves the modification of a vegetative organ—usually the stem—for reproduction. Review Figure 38.17 • Horticulturists often graft different plants together to take advantage of favorable properties of both stock and scion. Review Figure 38.18

CHAPTER 39 Plant Responses to Environmental Challenges

39.1 How Do Plants Deal with Pathogens? • Plants and pathogens have evolved together in a continuing "arms race": pathogens have evolved mechanisms for attacking plants, and plants have evolved mechanisms for defending themselves against those attacks. • Constitutive defenses include plants' ability to strengthen their cell walls and block plasmodesmata when attacked, limiting the ability of viral pathogens to move from cell to cell. • Induced defenses are triggered by a wide range of molecular elicitors and fall into two main categories: general immunity and specific immunity. Review

Figure 39.2, ANIMATED TUTORIAL 39.1 • The gene-for-gene concept depends on a match between a plant's resistance (R) genes and a pathogen's Avirulence (Avr) genes. Review Figure 39.3 • In the hypersensitive response to infection by bacteria or fungi, cells produce two kinds of defensive molecules: phytoalexins and pathogenesis-related (PR) proteins. Some cells around the infected area die, sealing off the pathogens and the damage they have caused. • The hypersensitive response is often followed by systemic acquired resistance, in which salicylic acid activates further synthesis of defensive compounds. • Plants use RNA interference to develop specific immunity to invading RNA viruses.

39.2 How Do Plants Deal with Herbivores? • Some plants produce secondary metabolites as defenses against herbivores. Review Table 39.1, Figure 39.6 • Hormones, including jasmonates, participate in signal transduction pathways leading to the production of defensive compounds. Review Figure 39.7 • Plants protect themselves against their own toxic defensive chemicals by isolating them in specialized compartments, by producing them only after the plant has already been damaged, or by having modified enzymes or receptors that are not affected by the toxic substance.

39.3 How Do Plants Deal with Environmental Stresses? • Plants cope with environmental stresses by adaptation (genetically encoded resistance) or acclimation (increased tolerance) Review Table 39.2 • Xerophytes are plants that are adapted to dry environments

• Some xerophytic adaptations are structural, including thickened cuticles, specialized trichomes, stomatal crypts, succulence, and long taproots. • Some plants accumulate solutes, making their water potential lower so they can tolerate drought. • Adaptations to water-saturated habitats include pneumatophores, extensions of roots that allow oxygen uptake from the air, and aerenchyma, tissue in which oxygen can be stored and ready for diffusion throughout the plant. • A signaling pathway involving abscisic acid initiates a plant's response to drought stress. Review Figures 39.14, 39.15 • Membranes and proteins can be damaged by extremely high or low temperatures. Plants respond to extreme temperatures by producing heat shock proteins. • Some plants undergo cold-hardening, an acclimation process that includes changes in membrane lipids and production of heat shock proteins. • Some plants resist freezing by producing antifreeze proteins.

39.4 How Do Plants Deal with Salt and Heavy Metals? • Most halophytes accumulate salt. Some have salt glands that excrete salt to the leaf surface. • Some plants living in soils that are rich in heavy metals are hyperaccumulators that take up large amounts of those metals into their tissues. • Phytoremediation is the use of hyperaccumulating plants or their genes to clean up environmental pollution. See ACTIVITY 39.1 for a concept review of this chapter.

PART NINE, ANIMALS: FORM AND FUNCTION

CHAPTER 40 Physiology, Homeostasis, and Temperature Regulation

40.1 How Do Multicellular Animals Supply the Needs of Their Cells? • Multicellular animals provide for the needs of all their cells by maintaining a stable internal environment. That environment consists of two extracellular fluid compartments: the interstitial fluid and the blood plasma. Review Figure 40.1 •

Regulation of physiological systems is mostly through negative feedback. Feedforward information functions to change set points. Review Figure 40.2

40.2 What Are the Relationships between Cells, Tissues, and Organs? • The cells of the body are organized into assemblages called tissues. • Although there are many cell types, there are only four tissue types: epithelial, muscle, connective, and neural tissues. • Organs are made up of tissues, and most organs contain all four types of tissues. Organs are grouped into organ systems. Review Figure 40.7

40.3 How Does Temperature Affect Living Systems? • Life is possible only within a narrow range of environmental temperatures. Q10 is a measure of the sensitivity of a life process to temperature. A Q10 of 2 means that the reaction rate of that process doubles as temperature increases by 10°C. Review Figure 40.8 • Animals can acclimatize to seasonal changes in temperature through biochemical and physiological adaptations. Review Figure 40.9

40.4 How Do Animals Alter Their Heat Exchange with the Environment? • The body temperatures of ectotherms are determined primarily by external sources of heat. Endotherms regulate their body temperatures by producing heat metabolically. Review Figure 40.10 • The four avenues of heat exchange with the environment are radiation, convection, conduction, and evaporation. The balance between heat production and heat exchange can be expressed as an energy budget. Review Figure 40.12 • Control of blood flow to the skin is an important means of temperature regulation. Circulatory system adaptations such as countercurrent heat exchange can conserve metabolic heat. Review Figures 40.13, 40.14

40.5 How Do Endotherms Regulate Their Body Temperatures? • Within the thermoneutral zone, resting endotherms have a basal metabolic rate (BMR) that scales with body size. Review Figures 40.16, 40.17, ACTIVITY 40.1 • In mammals, control of body temperature relies on commands from a regulatory center in the hypothalamus. This thermostat uses its own temperature as negative feedback information and skin temperature as feedforward information. Review Figure 40.20, ANIMATED TUTORIAL 40.1

CHAPTER 41 Animal Hormones

41.1 What Are Hormones and How Do They Work? • Endocrine cells secrete chemical signals that induce responses in other cells that have receptors for those molecules. In some cases endocrine cells are aggregated into endocrine glands. • Hormones are endocrine signals that are secreted from a cell, circulate in the blood, and bind to target cells distant from the secreting cell. Review Figure 41.1 • Hormones fall into three general categories: proteins and peptides, steroids, and amines. Peptide and protein hormones and some amines are water-soluble; steroids and some amines are lipid-soluble. Review Figure 41.2 • Receptors for water-soluble hormones are located on the cell surface. Receptors for most lipid-soluble hormones are inside the cell. • Hormones can cause different responses in different target cells. Review Figure 41.3

41.2 What Have Experiments Revealed about Hormones and Their Action? • The chemical structures of hormones are highly conserved. Through evolution, however, hormones acquire different functions in different animal groups. Review Figure 41.4 • Early experiments identifying secretin as a hormone defined the characteristics of hormonal signaling. Modern experiments demonstrate these characteristics in order to identify hormone molecules. Review Figure 41.5 • Pioneering experiments

illustrating hormonal action showed that two hormones, PTTH and ecdysone, control molting in arthropods. A third hormone, juvenile hormone, prevents maturation. Review Figures 41.6, 41.7, ANIMATED TUTORIAL 41.1

41.3 How Do the Nervous and Endocrine Systems Interact? • In humans, the major endocrine glands are distributed around the body. Review Figure 41.8, ACTIVITY 41.1 • The pituitary gland is the interface between the nervous and endocrine systems. The anterior pituitary develops from embryonic mouth tissue; the posterior pituitary develops from the developing brain. Review Figures 41.9, 41.10 • The posterior pituitary secretes two neurohormones: antidiuretic hormone (ADH) and oxytocin. The anterior pituitary secretes tropic hormones (thyrotropin, corticotropin, luteinizing hormone, and follicle-stimulating hormone) as well as growth hormone, prolactin, endorphins, and enkephalins. • The anterior pituitary is controlled by neurohormones produced by cells in the hypothalamus and transported through portal blood vessels to the anterior pituitary. See ANIMATED TUTORIAL 41.2 • Hormone release is controlled in part by negative feedback loops. Review Figure 41.11

41.4 What Are the Major Endocrine Glands and Hormones? • The thyroid gland is controlled by thyrotropin and secretes thyroxine, which controls cell metabolism. Review Figure 41.12 • The level of calcium in the blood is regulated by three hormones. Calcitonin from the thyroid lowers blood calcium by promoting bone deposition. Parathyroid hormone (PTH) raises blood calcium by promoting bone turnover and decreasing calcium excretion. Calcitriol promotes calcium absorption from the digestive tract. Review Figure 41.14, ANIMATED TUTORIAL 41.3 • The pancreas secretes three hormones. Insulin stimulates glucose uptake by cells and lowers blood glucose, glucagon raises blood glucose, and somatostatin slows the rate of nutrient processing. • The adrenal gland has two portions, one within the other. The inner portion, the adrenal medulla, releases epinephrine and norepinephrine in response to stress. The outer portion, the adrenal cortex, produces three classes of corticosteroids: glucocorticoids, mineralocorticoids, and small amounts of sex steroids. Review Figure 41.15 • Aldosterone is a mineralocorticoid that stimulates the kidneys to conserve sodium and excrete potassium. Cortisol is a glucocorticoid that is released in response to stressful stimuli but acts more slowly than the hormones of the adrenal medulla. • Sex hormones (androgens in males, estrogens and progesterone in females) control sexual development, secondary sexual characteristics, and reproductive functions. Review Figure 41.17 • The pineal gland releases melatonin, a hormone involved in controlling biological rhythms. Review Figure 41.18

41.5 How Do We Study Mechanisms of Hormone Action? • Immunoassay techniques are used to measure concentrations of hormones and other substances. Review Figure 41.19 • The body's sensitivity to a hormone is measured by a dose– response curve. Review Figure 41.20 • The sensitivity of a cell to a hormone can be altered by downregulation or upregulation of the hormone's receptors in that cell. See ACTIVITY 41.2 for a concept review of this chapter

CHAPTER 42 Immunology: Animal Defense Systems

42.1 What Are the Major Defense Systems of Animals? • Animal defenses against pathogens are based on the body's ability to distinguish between self and non-self. • Innate (nonspecific) defenses are inherited mechanisms that protect the body from many kinds of pathogens. They typically act rapidly. • Adaptive (specific) defenses respond to specific pathogens. They develop more slowly than innate

defenses but are long-lasting. • Many defenses are implemented by cells and proteins carried in the blood plasma and lymph. Review Figure 42.1, ACTIVITY 42.1 • White blood cells fall into two broad groups. Phagocytes engulf pathogens by phagocytosis. Lymphocytes, which include B cells and T cells, participate in adaptive responses. Review Figure 42.2, ANIMATED TUTORIAL 42.1

42.2 What Are the Characteristics of the Innate Defenses? • An animal's innate defenses include physical barriers such as the skin, and competing resident microorganisms known as normal flora. Review Figure 42.3 • The complement system consists of more than 20 different antimicrobial proteins that act to alter membrane permeability and kill targeted cells. • Circulating defensive cells, such as phagocytes and natural killer cells, eliminate invaders. • A cell signaling pathway involving the toll-like receptor stimulates the body's defenses. Review Figure 42.4 • Inflammation involves activation of several types of cells and proteins that act against invading pathogens. Mast cells release histamines, which cause blood vessels to dilate and become "leaky." Review Figure 42.5, ACTIVITY 42.2

42.3 How Does Adaptive Immunity Develop? • The adaptive immune response recognizes specific antigens, responds to an enormous diversity of antigenic determinants, distinguishes self from non-self, and remembers the antigens it has encountered. Review ANIMATED TUTORIAL 42.2 • Each antibody and each T cell is specific for a single antigenic determinant. T cell receptors bind to antigens on the surfaces of virus-infected cells and abnormal cells. • The humoral immune response is directed against pathogens in the blood, lymph, and tissue fluids. The cellular immune response is directed against an antigen established within a host cell. Both responses are mediated by antigenic fragments being presented on a cell surface along with the proteins of the major histocompatibility complex (MHC). Review Figure 42.7 • Clonal selection accounts for the specificity and diversity of the immune response and for immunological memory. Review Figure 42.8 • An activated B or T lymphocyte produces effector cells that attack the antigen, and memory cells that are long-lived and rarely divide. Effector B cells are called plasma cells and secrete specific antibodies. • Vaccination is inoculation with modified pathogens or antigens that provoke an immune response but are not pathogenic. Review Figure 42.9

42.4 What Is the Humoral Immune Response? See ANIMATED TUTORIAL 42.3 • B cells are the basis of the humoral immune response. Naïve B cells are activated by binding of antigen and by stimulation by TH cells with the same specificity, and then form plasma cells. These cells synthesize and secrete specific antibodies. • An antibody is an immunoglobulin, a tetramer of four polypeptides: two identical light chains and two identical heavy chains, each consisting of a constant region and a variable region. Review Figure 42.10, ACTIVITY 42.3 • The variable regions determine the specificity of an immunoglobulin, and the constant regions of the heavy chain determine its class. There are five classes of immunoglobulins with different body locations and functions. Review Table 42.2 • B cell genomes undergo random recombination of genes coding for regions of the immunoglobulin polypeptide chains so that each cell can produce a specific antibody protein. The immunoglobulin chains derive from "supergenes" that are constructed from different combinations of V, D, J, and C genes. This DNA rearrangement and rejoining yields millions of different immunoglobulin chains. Review Figures 42.11, 42.12, ANIMATED TUTORIAL 42.4 • Once a B cell becomes a plasma cell, it may undergo class switching, in which a deletion of one or more constant region genes results in the production of an immunoglobulin with a different constant region and a different function. Review Figure 42.13 • A monoclonal antibody can be used in diagnosis and therapy.

42.5 What Is the Cellular Immune Response? See ANIMATED TUTORIAL 42.5 • T cells are the effectors of the cellular immune response. T cell receptors are somewhat similar in structure to the immunoglobulins, having variable and constant regions. Review Figure 42.14 • There are three types of T cells. Cytotoxic T cells (TC cells) recognize and kill virus-infected cells or mutated cells. T-helper cells (TH cells) direct both the cellular and humoral immune responses. Regulatory T cells (Tregs) inhibit the other T cells from mounting an immune response to self antigens. • The genes of the major histocompatibility complex (MHC) encode membrane proteins that bind antigenic fragments and present them to T cells. Review Figures 42.15, 42.16 • Organ transplants are rejected when the host's immune system recognizes MHC proteins on transplanted tissue as non-self and initiates an immune defense attacking the foreign tissue.

42.6 What Happens When the Immune System Malfunctions? • An allergic reaction is an inappropriate immune response caused by immediate hypersensitivity or delayed hypersensitivity to certain antigens. Review Figure 42.18 • Autoimmune diseases result when the immune system produces B and T cells that attack self antigens. • Immune deficiency disorders result from failure of one or another part of the immune system. Acquired immune deficiency syndrome (AIDS) is a disorder that arises from depletion of the TH cells as a result of infection with human immunodeficiency virus (HIV). Review Figure 42.19

CHAPTER 43 Animal Reproduction

43.1 How Do Animals Reproduce without Sex? • Asexual reproduction produces offspring that are genetically identical to their parent and to one another; it produces no genetic diversity. • Means of asexual reproduction include budding, regeneration, and parthenogenesis. Review Figures 43.1, 43.2

43.2 How Do Animals Reproduce Sexually? • Sexual reproduction involves three basic steps: gametogenesis, spawning or mating, and fertilization. • Gametogenesis and fertilization are similar in all animals, but spawning and mating include a great variety of anatomical, physiological, and behavioral adaptations. • Gametogenesis occurs in testes and ovaries. In spermatogenesis (the production of sperm) and oogenesis (the production of eggs), the germ cells proliferate mitotically, undergo meiosis, and mature into gametes. • Each primary spermatocyte can produce four haploid sperm through the two divisions of meiosis. Review Figure 43.3A • Primary oocytes immediately enter prophase of the first meiotic division, and in many species, including humans, their development is arrested at this point. Each oogonium produces only one egg. Review Figure 43.3B • Fertilization involves sperm activation, species-specific binding of sperm to egg, the acrosomal reaction, digestion of a path through the protective coverings of the egg, and fusion of sperm and egg plasma membranes. Fusion of these two membranes triggers blocks to polyspermy, which prevent additional sperm from entering the egg and, in mammals, signal the egg to complete meiosis and begin development. Review Figure 43.4, ANIMATED TUTORIAL 43.1 • External fertilization is common in aquatic species. Internal fertilization is necessary in terrestrial species and usually involves copulation. • Hermaphroditic, or monoecious, species have both male and female reproductive systems in the same individual, either sequentially or simultaneously. Dioecious species have separate male and female individuals. • Animals can be classified as oviparous or viviparous, depending on whether the early stages of development occur outside or inside the mother's body.

43.3 How Do the Human Male and Female Reproductive Systems Work? • Men produce semen consisting of sperm suspended in seminal fluid (which nourishes the sperm and facilitates fertilization). • Sperm are generated in the seminiferous tubules of the testes, mature in the epididymis, and are delivered to the urethra through the vasa deferentia. Other components of semen are produced in the seminal vesicles, prostate gland, and bulbourethral gland. Review Figures 43.8, 43.9, ACTIVITIES 43.1, 43.2 • All components of the semen join in the urethra at the base of the penis and are ejaculated through the erect penis by muscle contractions at the culmination of copulation. • Spermatogenesis depends on testosterone secreted by the Leydig cells of the testes, which are under the control of hormones produced in the anterior pituitary and the hypothalamus. The production of these hormones is controlled by negative feedback from testosterone and from inhibin, a hormone produced by the Sertoli cells of the testes. Review Figure 43.10 • Eggs mature in the woman's ovaries and are released into the oviducts. Sperm deposited in the vagina during copulation move up through the cervix and uterus into the oviducts. Fertilization occurs in the upper regions of the oviducts. Review Figure 43.11, ACTIVITY 43.3 • The maturation and release of eggs constitute an ovarian cycle. The uterine cycle prepares the uterus for receipt of a blastocyst. If no blastocyst is implanted, the lining of the uterus sloughs off in the process of menstruation. Review Figure 43.13, ANIMATED TUTORIAL 43.2 • Both the ovarian and the uterine cycles are under the control of hypothalamic and pituitary hormones, which in turn are under the feedback control of estrogen and progesterone. Review Figure 43.14 • Childbirth is initiated by hormonal and mechanical stimuli that increase the contraction of uterine muscle. Review Figure 43.15

43.4 How Can Fertility Be Controlled? • Methods of contraception include abstention from copulation and the use of technologies that decrease the probability of fertilization. Review Table 43.1 • Assisted reproductive technologies (ARTs) have been developed to increase fertility.

CHAPTER 44 Animal Development

44.1 How Does Fertilization Activate Development? • The sperm and the egg contribute differentially to the zygote. The sperm contributes a haploid nucleus and, in most species, a centriole. The egg contributes a haploid nucleus, nutrients, ribosomes, mitochondria, mRNAs, and proteins. • In amphibians, the cytoplasmic contents of the egg are not distributed homogeneously, and they are rearranged after fertilization to set up the major axes of the future embryo. The nutrient molecules are generally found in the vegetal hemisphere, whereas the nucleus is found in the animal hemisphere. Review Figures 44.1, 44.2

44.2 How Does Mitosis Divide Up the Early Embryo? • Cleavage is a period of rapid cell division. Except in mammals, little if any gene expression occurs during cleavage. Cleavage can be complete or incomplete, and the pattern of cell divisions depends on the orientation of the mitotic spindles. The result of cleavage is a ball or mass of cells called a blastula. Review Figure 44.3 • Early cell divisions in mammals are unique in being slow and allowing for gene expression early in the process. These cell divisions produce a blastocyst composed of an inner cell mass that becomes the embryo and an outer cell mass that develops as the trophoblast. At the time of implantation, the trophoblast secretes molecules that help the blastocyst implant in the uterine wall. Review Figures 44.4, 44.5 • A fate map can be created by labeling specific blastomeres and observing what tissues and organs are formed by their progeny. Review Figure 44.6 • Some species undergo mosaic development, in which the fate of

each cell is determined during early divisions. Other species, including vertebrates, undergo regulative development, in which remaining cells can compensate for cells lost in early cleavages.

44.3 How Does Gastrulation Generate Multiple Tissue Layers? • Gastrulation involves massive cell movements that produce three germ layers and place cells from various regions of the blastula into new associations with one another. Review Figure 44.7, ANIMATED TUTORIAL 44.1 • The initial step of sea urchin and amphibian gastrulation is inward movement of certain blastomeres. The site of inward movement becomes the blastopore. Cells that move into the blastula become the endoderm and mesoderm; cells remaining on the outside become the ectoderm. Cytoplasmic factors in the vegetal pole cells are essential to initiate development. Review Figures 44.7, 44.8 • The dorsal lip of the amphibian blastopore is a critical site for cell determination. It has been called the primary embryonic organizer because it induces determination in cells that pass over it during gastrulation. Review Figures 44.8, 44.9, 44.10, ANIMATED TUTORIAL 44.2

• The protein β-catenin activates a signaling cascade that induces the primary embryonic organizer and sets up the anterior– posterior body axis. Review Figures 44.2, 44.11 • Gastrulation in reptiles and birds differs from that in sea urchins and frogs because the large amount of yolk causes the blastula to form a flattened disc of cells. Review Figure 44.13 • Although their eggs have no yolk, placental mammals have a pattern of gastrulation similar to that of reptiles and birds.

44.4 How Do Organs and Organ Systems Develop? • Gastrulation is followed by organogenesis, the process whereby tissues interact to form organs and organ systems. • In the formation of the vertebrate nervous system, one group of cells that migrates over the blastopore lip is determined to become the notochord. The notochord organizes the overlying ectoderm to thicken, form parallel ridges, and fold in on itself to form a neural tube below the epidermal ectoderm. The nervous system develops from this neural tube. Review Figure 44.14 • The notochord and neural crest cells participate in the segmental organization of mesoderm into structures called somites along the body axis. Rudimentary organs and organ systems form during these stages. Review Figure 44.15 • In vertebrates, Hox genes determine the pattern of anterior–posterior differentiation along the body axis. Other genes, such as Sonic hedgehog, contribute to dorsal–ventral differentiation. Review Figure 44.16

44.5 How Is the Growing Embryo Sustained? • The embryos of reptiles, birds, and mammals are protected and nurtured by four extraembryonic membranes. In birds and reptiles the yolk sac surrounds the yolk and provides nutrients to the embryo, the chorion lines the eggshell and participates in gas exchange, the amnion surrounds the embryo and encloses it in an aqueous environment, and the allantois stores metabolic wastes. Review Figure 44.17, ACTIVITY 44.1 • In mammals the chorion and the trophoblast cells interact with the maternal uterus to form a placenta, which provides the embryo with nutrients and gas exchange. The amnion encloses the embryo in an aqueous environment. Review Figure 44.18

44.6 What Are the Stages of Human Development? • Human pregnancy, or gestation, can be divided into three trimesters. The embryo forms in the first trimester; during this time, it is most vulnerable to environmental factors that can lead to birth defects. During the second and third trimesters the fetus grows, the limbs elongate, and the organ systems mature. • Development continues throughout childhood and throughout life.

CHAPTER 45 Neurons, Glia, and Nervous Systems

45.1 What Cells Are Unique to the Nervous System? • The cells of the nervous systems include many types of neurons and glia. • All neurons are excitable, which means they can generate and conduct electric signals called action potentials. Glia support and modulate the activities of neurons but do not generate action potentials. • A neuron generally receives information via its dendrites, of which there can be many, and transmits information via its single axon, which ends in axon terminals. Review Figure 45.1 • Where neurons and their target cells meet, information is transmitted across specialized junctions called synapses. • Glia include Schwann cells and oligodendrocytes, both of which generate myelin sheets on axons. Glia also include astrocytes, which support neurons metabolically, modulate synaptic signaling, and contribute to the blood–brain barrier. Review Figures 45.3, 45.4

45.2 How Do Neurons Generate and Transmit Electric Signals? • Neurons have an electric charge difference across their plasma membranes, the membrane potential. The membrane potential is created by ion transporters and channels. When a neuron is not firing action potentials, its membrane potential is referred to as the resting potential. Review Figures 45.5, 45.6, ANIMATED TUTORIAL 45.1 • The sodium–potassium pump concentrates K^+ on the inside of a neuron and Na^+ on the outside. Potassium leak channels allow K^+ to diffuse out of the neuron, leaving behind unbalanced negative charges. Review Figures 45.6, 45.7 • Patch clamping allows the study of single ion channels. Review Figure 45.8 • The resting potential is perturbed when ion channels open or close, changing the permeability of the plasma membrane to charged ions. Through this mechanism, the plasma membrane can become depolarized or hyperpolarized and therefore have a graded membrane potential response to input. Review Figure 45.9 • An action potential results from a rapid reversal in charge across a portion of the plasma membrane resulting from the sequential opening and closing of voltage-gated Na^+ and K^+ channels. These changes in voltage-gated channels occur when the plasma membrane depolarizes to a threshold level. Review Figure 45.10, ANIMATED TUTORIAL 45.2 • Action potentials are all-or-none, self-regenerating events. They are conducted down axons because local current flow depolarizes adjacent regions of membrane and brings them to threshold. Review Figure 45.11 • In myelinated axons, action potentials appear to jump between nodes of Ranvier, areas of axonal plasma membrane that are not covered by myelin. Review Figure 45.12

45.3 How Do Neurons Communicate with Other Cells? • Neurons communicate with each other and with other cell types by transmitting information over electrical synapses or by the transmission of molecular signals called neurotransmitters over chemical synapses. • The neuromuscular junction is a well-studied chemical synapse between a motor neuron and a skeletal muscle cell. Its neurotransmitter is acetylcholine (ACh), which causes depolarization of the postsynaptic membrane when it binds to its receptor at the motor end plate. Review Figure 45.13, ANIMATED TUTORIAL 45.3 • When an action potential reaches an axon terminal, it causes the release of neurotransmitters, which diffuse across the synaptic cleft and bind to receptors on the postsynaptic membrane. Review Figures 45.13, 45.14, ANIMATED TUTORIAL 45.4 • Synapses between neurons can be either excitatory or inhibitory. A postsynaptic neuron integrates information by summing excitatory and inhibitory postsynaptic potentials in both spatially and temporally. Review Figure 45.15 • Ionotropic receptors are ion channels or directly influence ion channels. Metabotropic receptors influence the postsynaptic cell through various signal transduction pathways and can result in the opening or closing of ion channels. The actions of ionotropic synapses are generally faster than those of metabotropic synapses. • There are many different neurotransmitters and even more types of receptors. The action of a neurotransmitter

depends on the type of receptor to which it binds. See ACTIVITY 45.1 • Neurotransmitter molecules cannot be allowed to accumulate in a synapse but must be cleared in order to turn off responses in the postsynaptic cell. This may be done by enzymatic degradation, simple diffusion, or reuptake of the neurotransmitter.

45.4 How Are Neurons and Glia Organized into Information-Processing Systems? • In vertebrates, the brain and spinal cord form the central nervous system (CNS), which communicates with the rest of the body via the peripheral nervous system (PNS). The CNS increases in complexity from invertebrates to vertebrates and from fish to mammals. Review Figures 45.17, 45.19 • Neural networks include afferent neurons and efferent neurons, generally connected through interneurons. • A spinal reflex is an example of a simple neural network that integrates information and controls a response. Review Figure 45.18, ANIMATED TUTORIAL 45.5

CHAPTER 46 Sensory Systems

46.1 How Do Sensory Receptor Cells Convert Stimuli into Action Potentials? • Sensory receptor cells, also known as sensors or receptors, transduce information about an animal's external and internal environment into action potentials that the brain perceives as different forms of sensory information. • Receptor potentials can spread to regions of the cell's plasma membrane that generate action potentials. Some sensors do not fire action potentials but release neurotransmitter onto sensory neurons that do fire action potentials. Review Figure 46.1 • Sensors have receptor proteins that cause ion channels to open or close, affecting the receptor cell's membrane potential. Metabotropic receptors act through signal transduction pathways to generate receptor potentials. Mechanoreceptors are ionotropic sensory receptors that open ion channels physically through forces such as pressure or stretch. Review Figure 46.2 • The interpretation of action potentials as particular sensations depends on which neurons in the central nervous system receive them. • Adaptation enables the nervous system to ignore irrelevant or continuous stimuli while remaining responsive to relevant or new stimuli.

46.2 How Do Sensory Systems Detect Chemical Stimuli? • Chemoreceptors are responsible for olfaction, gustation, and the sensing of pheromones. • Mammalian olfactory receptor neurons (ORNS) project directly to the olfactory bulb of the brain. ORNs for the same odorant project to the same area of the olfactory bulb. • Each ORN expresses one receptor protein that can bind a specific type of molecule or ion. Binding causes a second messenger to open ion channels, which creates an action potential. Review Figure 46.3 • In vertebrates, taste buds in the mouth cavity are responsible for gustation. The five basic tastes are sweet, salty, sour, bitter, and umami. Review Figure 46.5

46.3 How Do Sensory Systems Detect Mechanical Forces? • The skin contains a variety of ionotropic mechanoreceptors that respond to touch and pressure. The density of mechanoreceptors in any skin area determines the sensitivity of that area. Review Figure 46.6 • Stretch receptors in muscle spindles and in the Golgi tendon organ inform the CNS of the positions of and loads on parts of the body. Review Figure 46.7 • Hair cells are mechanoreceptors of the auditory and vestibular systems. Physical bending of their stereocilia alters their receptor proteins and therefore their membrane potentials. Review Figure 46.8 • In mammalian auditory systems, ear pinnae collect and direct sound waves to the tympanic membrane, which vibrates in response to sound waves. The movements of the tympanic membrane are amplified through a chain of ossicles that conduct the vibrations to the oval window.

Movements of the oval window create pressure waves in the fluid-filled cochlea. Review Figure 46.9, ACTIVITY 46.1 • The basilar membrane running down the center of the cochlea is distorted by pressure waves at specific locations that depend on the frequency of the wave. These distortions cause hair cells in the organ of Corti to bend and to release neurotransmitter, generating action potentials in the cochlear nerve that are transmitted to the auditory cortex of the brain. Review Figure 46.10, ANIMATED TUTORIAL 46.1 • Hair cells are also the mechanoreceptors of the organs of equilibrium in the mammalian vestibular system, which include the semicircular ducts and the saccule and utricle. Review Figure 46.11, ANIMATED TUTORIAL 46.2

46.4 How Do Sensory Systems Detect Light? • Photosensitivity depends on the absorption of photons of light by visual pigment molecules that consist of a protein called opsin and a light-absorbing group. Absorption of light is the first step in a cascade of intracellular events leading to a change in the membrane potential of the photoreceptor cell. Review Figure 46.12, ANIMATED TUTORIAL 46.3 • Visual systems range from the simple eye cups of flatworms, which sense the direction of a light source, to the compound eyes of arthropods, which detect shapes and patterns, to the image-forming eyes of vertebrates and cephalopods. Review Figures 46.13, 46.14 • Vertebrate and cephalopod eyes focus detailed images of the visual field onto dense arrays of photoreceptors that transduce the visual image into neural signals. Review Figures 46.14, 46.15, ACTIVITY 46.2 • Vertebrates have two types of photoreceptors, rod cells and cone cells. Rod cells are more sensitive to light and are responsible for dim light vision. Cone cells are less sensitive to light but are responsible for high-acuity and color vision. • Photoreceptors do not fire action potentials. When not stimulated by light they release neurotransmitter continuously. Light hyperpolarizes rod cells, and their release of neurotransmitter decreases. Review Figures 46.17, 46.18 • Rhodopsin is the visual pigment of rod cells. The visual pigments of cone cells have three different opsin components, which gives them different spectral sensitivities. Review Figure 46.19 • The vertebrate retina consists of layers of neurons lining the back of the eye. The light-absorbing photoreceptor cells are at the rear of the retina. The axons of the ganglion cells are bundled together in the optic nerve. Between the photoreceptors and the ganglion cells are neurons that process information from the photoreceptors. Review Figure 46.20, ACTIVITY 46.3

CHAPTER 47 The Mammalian Nervous System: Structure and Higher Functions

47.1 How Is the Mammalian Nervous System Organized? • The brain and spinal cord make up the central nervous system (CNS); the cranial and spinal nerves make up the peripheral nervous system (PNS). • The nervous system can be modeled conceptually in terms of the direction of information flow and whether we are conscious of the information. The afferent component carries information from the PNS to the CNS, and the efferent component directs information from the CNS to the peripheral parts of the body. Review Figure 47.1 • The vertebrate nervous system develops from a hollow dorsal neural tube. The brain forms from three swellings at the anterior end of the neural tube, which become the hindbrain, the midbrain, and the forebrain. The forebrain develops into the cerebral hemispheres (the telencephalon, or cerebrum) and the underlying thalamus and hypothalamus (which together compose the diencephalon). The midbrain and hindbrain develop into the brainstem and the cerebellum. Review Figure 47.2 • The spinal cord communicates information between the brain and the rest of the body. • The reticular activating system is a complex network that directs incoming information to appropriate brainstem nuclei that control autonomic functions, and transmits the information to the forebrain that

results in conscious sensation. The reticular activating system controls the level of arousal of the nervous system, including sleep and wakefulness. • The limbic system is an evolutionarily primitive part of the telencephalon that is involved in emotions, physiological drives (such as hunger and thirst), instincts, and memory. Review Figure 47.3

• The cerebral hemispheres are the dominant structures of the human brain. Their surfaces are layers of neurons called the cerebral cortex. The cerebral hemispheres can be divided into the temporal, frontal, parietal, and occipital lobes. Many motor functions are localized in parts of the frontal lobe. Information from many sensory receptors projects to a region of the parietal lobe. Visual information projects to the occipital lobe, and auditory information projects to a region of the temporal lobe. Review Figures 47.4, 47.5, 47.6, ACTIVITY 47.1

47.2 How Is Information Processed by Neural Networks? • The autonomic nervous system (ANS) consists of efferent pathways that control the physiological function of organs and organ systems. Its sympathetic and parasympathetic divisions are characterized by their anatomy, neurotransmitters, and effects on target tissues. Review Figure 47.9 • The neural network of vision involves patterns of light falling on receptive fields in the retina. Receptive fields have a center and a surround, which have opposing effects on ganglion cell firing. Review Figure 47.10, ANIMATED TUTORIALS 47.1, 47.2 • Information from retinal ganglion cells is communicated via the optic nerve to the thalamus and then to the visual cortex. The visual cortex seems to assemble an image of the visual world by analyzing edges of patterns of light. • Binocular vision is possible because information from both eyes is communicated to binocular cells in the visual cortex. These cells interpret distance by measuring the disparity between where the same stimulus falls on the two retinas. Review Figure 47.11

47.3 Can Higher Functions Be Understood in Cellular Terms? • Humans have a daily cycle of sleep and waking. Sleep can be divided into rapid eye movement (REM) sleep and non-REM sleep. Deep non-REM sleep is known as slow-wave sleep because of its characteristic EEG patterns. Review Figure 47.12 • Language abilities are localized mostly in the left cerebral hemisphere, a phenomenon known as lateralization. Different areas of the left hemisphere—including Broca's area, Wernicke's area, and the angular gyrus—are responsible for different aspects of language. Review Figures 47.13, 47.14, ACTIVITY 47.2 • Some learning and memory processes have been localized to specific brain areas. Long-lasting changes in synaptic properties referred to as long-term potentiation (LTP) and long-term depression (LDP) may be involved in learning and memory. • Complex memories can be elicited by stimulating small regions of association cortex. Damage to the hippocampus can destroy the ability to form long-term declarative memory but not procedural memory. • A sense of the physiological state of the body may be created in the insula of the cortex from visceral afferent information. Evolution of this integrative function in higher primates and humans could be the basis for conscious experience. See ACTIVITY 47.3 for a concept review of this chapter

CHAPTER 48 Musculoskeletal Systems

48.1 How Do Muscles Contract? • Skeletal muscle consists of bundles of muscle fibers. Each skeletal muscle fiber is a large cell containing multiple nuclei. • Skeletal muscles contain numerous myofibrils, which are bundles of actin and myosin filaments. The regular, overlapping arrangement of the actin and myosin filaments into sarcomeres gives skeletal muscle its striated appearance. Review Figure 48.1,

ACTIVITY 48.1 • The changes in the banding patterns of sarcomeres led to the sliding filament model of muscle contraction. Review Figure 48.2 • The molecular mechanism of muscle contraction involves the binding of the globular heads of myosin molecules to actin. Review Figures 48.3, 48.6, ANIMATED TUTORIAL 48.1 • All the fibers activated by a single motor neuron constitute a motor unit. Each nerve ending of the motor neuron forms a synapse with the muscle cell membrane. Action potentials spread across the muscle cell membrane and through the T tubules, causing Ca^{2+} to be released from the sarcoplasmic reticulum. Review Figure 48.5, ACTIVITY 48.2 • Ca^{2+} binds to troponin and changes its conformation, pulling the tropomyosin strands away from the myosin-binding sites on the actin filament. The muscle fiber continues to contract until the Ca^{2+} is returned to the sarcoplasmic reticulum. Review Figure 48.6 • Cardiac muscle cells are striated, uninucleate, branching, and electrically connected by gap junctions, so that action potentials spread rapidly throughout sheets of cardiac muscle and cause coordinated contractions. • Smooth muscle provides contractile force for internal organs. Smooth muscle cells respond to stretch and to neurotransmitters from the autonomic nervous system. Review Figure 48.8, ANIMATED TUTORIAL 48.2

48.2 What Determines Muscle Performance? • In skeletal muscle, a single action potential causes a minimum unit of contraction called a twitch. Twitches occurring in rapid succession can be summed to achieve sustained tension, known as tetanus. Review Figure 48.10 • Slow-twitch fibers facilitate extended, aerobic work; fast twitch fibers generate maximum forces for short periods of time. The ratio of slow-twitch to fast-twitch fibers in the muscles of an individual is largely genetically determined. Review Figure 48.11 • The force that a muscle fiber can produce depends on its initial state of extension or contraction. Review Figure 48.12 • Anaerobic exercise stimulates the enlargement of muscle fibers through production of new microfilaments. Aerobic exercise stimulates greater oxidative capacity of muscle fibers. • Muscle performance depends on a supply of ATP. Review Figure 48.13

48.3 How Do Skeletal Systems and Muscles Work Together? • Skeletal systems provide supports against which muscles can pull. • Hydrostatic skeletons are fluid-filled body cavities that can be squeezed by muscles. Review Figure 48.14 • Exoskeletons are hardened outer surfaces to which internal muscles are attached. • Endoskeletons are internal systems of rigid rodlike, platelike, and tubelike supports, consisting of bone and cartilage to which muscles are attached. Review Figure 48.15 • Bone is continually remodeled by osteoblasts, which lay down new bone, and osteoclasts, which erode bone. Review Figure 48.16 • Bones develop from connective tissue membranes (membranous bone) or from cartilage (cartilage bone) through ossification. Review Figure 48.17 • Bone can be compact (solid and hard) or cancellous (containing numerous internal spaces). Most of the compact bone of mammals is composed of Haversian systems. Review Figure 48.18 • Joints enable muscles to power movements in different directions. Muscles and bones work together around joints as systems of levers. Review Figures 48.19, 48.21, ACTIVITY 48.3 • Tendons connect muscles to bones; ligaments connect bones to one another. Review Figure 48.20

CHAPTER 49 Gas Exchange

49.1 What Physical Factors Govern Respiratory Gas Exchange? • Most cells require a constant supply of O_2 and continuous removal of CO_2. These respiratory gases are exchanged between an animal's body fluids and its environment by diffusion. • Fick's law of diffusion shows how various physical factors influence the diffusion rate of gases. Adaptations to maximize respiratory gas exchange influence one or

more variables of Fick's law. • In water-breathing animals, gas exchange is limited by the low diffusion rate and low amount of O_2 in water. If water temperature rises, water-breathing animals face a double bind in that the amount of O_2 in water decreases, but their metabolism and the amount of work required to move water over the gas exchange surfaces increase. Review Figure 49.2 • In air, the partial pressure of oxygen (PO_2) decreases with altitude.

49.2 What Adaptations Maximize Respiratory Gas Exchange? • Adaptations to maximize gas exchange include increasing the surface area for gas exchange and maximizing partial pressure gradients across those exchange surfaces by ventilating the outer surface with the respiratory medium, and perfusing the inner surface with blood. Review Figure 49.3 • Insects distribute air throughout their bodies in a system of tracheae, tracheoles, and air capillaries. Review Figure 49.4 • The gills of fishes have large gas exchange surface areas that are ventilated continuously and unidirectionally with water. The countercurrent flow of blood helps increase the efficiency of gas exchange. Review Figures 49.5, 49.6 • The gas exchange system of birds includes air sacs that communicate with the lungs but are not used for gas exchange. Air flows unidirectionally through bird lungs; gases are exchanged in air capillaries that run between parabronchi. Review Figure 49.7 • Each breath of air remains in a bird's respiratory system for two breathing cycles. The air sacs work as bellows to supply the air capillaries with a continuous unidirectional flow of fresh air. Review Figure 49.8, ANIMATED TUTORIAL 49.1 • In all air-breathing vertebrates except birds, breathing is tidal. This is a less efficient form of gas exchange than that of fishes and birds. Although the volume of air exchanged with each breath can vary considerably in tidal breathing, the inhaled air is always mixed with stale air. Review Figure 49.9

49.3 How Do Human Lungs Work? • In mammalian lungs, the gas exchange surface area provided by the millions of alveoli is enormous, and the diffusion path length between the air and perfusing blood is short. Surface tension in the alveoli would make inflation of the lungs difficult if the alveoli did not produce surfactant. Review Figure 49.10, ACTIVITY 49.1 • Inhalation occurs when contractions of the diaphragm increase volume and reduce pressure in the thoracic cavity, thereby pulling on the pleural membranes. Relaxation of the diaphragm increases pressure in the thoracic cavity and results in exhalation. Review Figure 49.11, ANIMATED TUTORIAL 49.2 • During periods of heavy metabolic demands such as strenuous exercise, the intercostal muscles, located between the ribs, increase the volume of air inhaled and exhaled.

49.4 How Does Blood Transport Respiratory Gases? • O_2 is reversibly bound to hemoglobin in red blood cells. Each hemoglobin molecule can carry a maximum of four O_2 molecules. Because of positive cooperativity, hemoglobin's affinity for O_2 depends on the PO_2 to which the hemoglobin is exposed. Therefore hemoglobin picks up O_2 as it flows through respiratory exchange structures and gives up O_2 in metabolically active tissues. Review Figure 49.12, ANIMATED TUTORIAL 49.3 • Myoglobin serves as an O_2 reserve in muscle. • There is more than one type of hemoglobin. Fetal hemoglobin has a higher affinity for O_2 than does adult hemoglobin, allowing fetal blood to pick up O_2 from the maternal blood in the placenta. Review Figure 49.13, ACTIVITY 49.2 • CO_2 is transported in the blood principally as bicarbonate ions (HCO_3 –). Review Figure 49.14

49.5 How Is Breathing Regulated? • The basic breathing rhythm is an involuntary function generated by neurons in the medulla and modulated by higher brain centers. The most important feedback stimulus for breathing is the level of CO_2 in the blood. Review Figures 49.16, 49.17 • The breathing rhythm is sensitive to feedback from chemoreceptors on the ventral surface of the medulla and in the carotid and

aortic bodies on the large vessels leaving the heart. Review Figure 49.18 See ACTIVITY 49.3 for a concept review of this chapter

CHAPTER 50 Circulatory Systems

50.1 Why Do Animals Need a Circulatory System? • The metabolic needs of the cells of many small animals are met by direct exchange of materials with the external medium. The metabolic needs of the cells of larger animals are met by a circulatory system that transports nutrients, respiratory gases, and metabolic wastes throughout the body. • In open circulatory systems, extracellular fluid leaves vessels and percolates through tissues. In closed circulatory systems, the blood is contained in a system of vessels. Closed circulatory systems have the ability to selectively direct blood, hormones, and nutrients to specific tissues. Review Figure 50.1

50.2 How Have Vertebrate Circulatory Systems Evolved? • The circulatory system of vertebrates consists of a heart and a closed system of vessels containing blood that is separate from the interstitial fluid. Arteries and arterioles carry blood from the heart; capillaries are the site of exchange between blood and interstitial fluid; venules and veins carry blood back to the heart. • The vertebrate circulatory system evolved from a single circuit in fishes to partially or completely separate pulmonary and systemic circuits in amphibians, reptiles, and mammals. • In the single-circuit system of fishes, blood flow is unidirectional and is propelled by one-way valves between the sinus venosus and the atrium, between the atrium and the ventricle, and between the ventricle and the bulbus arteriosus. • In birds and mammals, blood circulates through two completely separate circuits. The pulmonary circuit transports blood between the heart and lungs, and the systemic circuit transports oxygen rich blood between the heart and tissues. See ACTIVITY 50.1

50.3 How Does the Mammalian Heart Function? • The mammalian heart has four chambers. Valves in the heart prevent the backflow of blood. Review Figure 50.2, ACTIVITY 50.2 • The cardiac cycle has two phases: systole, in which the ventricles contract, and diastole, in which the ventricles relax. The sequential heart sounds (“lub-dup”) are made by the closing of the heart valves. Review Figure 50.3, ANIMATED TUTORIAL 50.1 • Blood pressure can be measured using a sphygmomanometer and a stethoscope. Review Figure 50.4 • Pacemaker cells of the sinoatrial node set the heart rate as a result of the properties of their ion channels. The autonomic nervous system controls heart rate: sympathetic activity increases heart rate, and parasympathetic activity decreases it by altering the rate of depolarization of the pacemaker cell resting membrane potentials following the termination of systole. Review Figures 50.5, 50.6 • The sinoatrial node controls the cardiac cycle by initiating a wave of depolarization in the atria, which is conducted to the ventricles through a system consisting of the atrioventricular node, bundle of His, and Purkinje fibers. Review Figure 50.7 • Sustained contraction of ventricular muscle cells is due to long duration action potentials that are generated by voltage-gated Na^+ and Ca^{2+} channels. Review Figures 50.8, Figure 50.9 • An electrocardiogram (ECG or EKG) records electrical events associated with the contraction and relaxation of the cardiac muscles. Review Figure 50.10

50.4 What Are the Properties of Blood and Blood Vessels? • Blood consists of a plasma portion (water, salts, and proteins) and a cellular portion (erythrocytes or red blood cells, platelets, and white blood cells). All of the cellular components are produced from stem cells in the bone marrow. Review Figure

50.11 • Erythrocytes transport oxygen. Their production in the bone marrow is stimulated by erythropoietin, which is produced in response to hypoxia (low oxygen levels) in the tissues. • Platelets, along with circulating proteins, are involved in blood clotting, which results in a meshwork of fibrin threads that help seal damaged vessels. Review Figure 50.12 • Abundant smooth muscle cells allow vessels to change their diameter, altering their resistance and thus blood flow. Arteries have elastic fibers that enable them to withstand high pressures. Review Figure 50.13, ACTIVITY 50.3 • Capillary beds are the site of exchange of materials between blood and tissue fluid. • Starling's forces suggest that blood volume is maintained in the capillary beds by an exchange of fluids driven by both blood pressure and osmotic pressure. Review Figure 50.15

• An accumulation of fluid in the extracellular spaces leads to edema. Bicarbonate ions in the blood plasma contribute to the osmotic forces that draw water back into capillaries. • The ability of a specific molecule to cross a capillary wall depends on the architecture of the capillary, the type of substance, and the concentration gradient between the blood and the tissue fluid. • Veins have a high capacity for storing blood. Aided by gravity, by contractions of skeletal muscle, and by the actions of breathing, they return blood to the heart. Review Figure 50.16 • The Frank–Starling law describes forces that increase cardiac output, such as stretch of the cardiac muscles cells caused by increased venous return. • The lymphatic system returns the interstitial fluid to the blood.

50.5 How Is the Circulatory System Controlled and Regulated? • Blood flow through capillary beds is controlled by local autoregulatory mechanisms, hormones, and the autonomic nervous system. Review Figure 50.18, ANIMATED TUTORIAL 50.2 • Blood pressure is controlled in part by the hormones ADH and angiotensin, which stimulate contraction of blood vessels. Review Figure 50.19 • Heart rate is controlled by the autonomic nervous system, which responds to information about blood pressure and blood composition that is integrated by regulatory centers in the medulla. Review Figure 50.20

CHAPTER 51 Nutrition, Digestion, and Absorption

51.1 What Do Animals Require from Food? • Animals are heterotrophs that derive their energy and molecular building blocks, directly or indirectly, from autotrophs. • Carbohydrates, fats, and proteins in food supply animals with energy. A measure of the energy content of food is the kilocalorie (kcal). Excess caloric intake is stored as glycogen and fat. Review Figure 51.2 • For many animals, food provides essential carbon skeletons that they cannot synthesize themselves. Review Figure 51.4 • Most researchers consider 8 amino acids to be essential for adult humans; some believe that infants require as many as 12 essential amino acids in their diet. Macronutrients are mineral elements needed in large quantities; micronutrients are needed in small amounts. Review Figure 51.5, Table 51.1, ACTIVITY 51.1 • Vitamins are organic molecules that must be obtained in food. Review Table 51.2, ACTIVITY 51.2 • Malnutrition results when any essential nutrient is lacking from the diet. Chronic malnutrition causes deficiency disease.

51.2 How Do Animals Ingest and Digest Food? • Animals can be characterized by how they acquire nutrients: saprobes and detritivores, or decomposers, depend on dead organic matter, filter feeders strain the aquatic environment for small food items, herbivores eat plants, and carnivores eat other animals. Behavioral and anatomical adaptations reflect these feeding strategies. See ACTIVITY 51.3 • Digestion involves the breakdown of complex food molecules into monomers that can be absorbed and

used by cells. In most animals, digestion takes place in a tubular gut. Review Figure 51.7 • Absorptive areas of the vertebrate gut are characterized by a large surface area produced by extensive folding and numerous villi and microvilli. Review Figure 51.8 • Hydrolytic enzymes break down proteins, carbohydrates, and fats into their monomeric units.

51.3 How Does the Vertebrate Gastrointestinal System Function? • The vertebrate gut can be divided into several compartments with different functions. Review Figure 51.9, ACTIVITY 51.4 • The cells and tissues of the vertebrate gut are organized in the same way throughout its length. The innermost tissue layer, the mucosa, is the secretory and absorptive surface. The submucosa contains blood and lymph vessels and a nerve network that is sensory and also controls gut secretions. External to the submucosa are two smooth muscle layers. Between the two muscle layers is another nerve network that controls the movements of the gut. Review Figure 51.10 • Swallowing is a reflex that pushes a bolus of food into the esophagus. Peristalsis and segmentation movements of the gut move the bolus down the esophagus and through the entire length of the gut. Sphincters block the gut at certain locations, but they relax as a wave of peristalsis approaches. Review Figure 51.11 • Digestion begins in the mouth, where amylase is secreted with the saliva. Digestion of protein begins in the stomach, where parietal cells secrete HCl and chief cells secrete pepsinogen, a zymogen that becomes pepsin when activated by low pH and autocatalysis. The mucosa also secretes mucus, which protects the tissues of the gut. Review Figure 51.12 • In the duodenum, pancreatic enzymes carry out most of the digestion of food. Bile from the liver and gallbladder emulsifies fats into micelles. Bicarbonate ions from the pancreas neutralize the pH of the chyme entering from the stomach to produce an environment conducive to the actions of pancreatic enzymes such as trypsin. Review Figure 51.13, Table 51.3 • Final enzymatic cleavage of polypeptides and disaccharides occurs among the microvilli of the intestinal mucosa. Amino acids, monosaccharides, and inorganic ions are absorbed by the microvilli. Specific transporter proteins are sometimes involved. Symporters often power the absorption of nutrients. • Fats broken down by lipases are absorbed mostly as monoglycerides and fatty acids and are resynthesized into triglycerides within the gut epithelium. The triglycerides are combined with cholesterol and phospholipids and coated with protein to form chylomicrons, which pass out of the mucosal cells and into lymphatic vessels in the submucosa. Review Figure 51.14, ANIMATED TUTORIAL 51.1 • Water and ions are absorbed in the large intestine as waste matter and consolidated into feces, which are periodically eliminated. • Microorganisms in some compartments of the gut digest materials that their host cannot. Review Figure 51.15

51.4 How Is the Flow of Nutrients Controlled and Regulated? • Autonomic reflexes coordinate activity of the digestive tract, which has an intrinsic nervous system that can act independently of the CNS. • The actions of the stomach and small intestine are largely controlled by the hormones gastrin, secretin, and cholecystokinin. Review Figure 51.16 • The liver plays a central role in directing the traffic of fuel molecules. In the absorptive state, the liver takes up and stores fats and carbohydrates, converting monosaccharides to glycogen or fats. The liver also takes up amino acids and uses them to produce blood plasma proteins, and can engage in gluconeogenesis. • Fat and cholesterol are shipped out of the liver as low-density lipoproteins. High-density lipoproteins act as acceptors of cholesterol and bring fat and cholesterol back to the liver. • Insulin largely controls fuel metabolism during the absorptive state and promotes glucose uptake as well as glycogen and fat synthesis. In the postabsorptive state, lack of insulin blocks the uptake and use of glucose by most cells of the body except neurons. If blood glucose levels fall, glucagon secretion increases, stimulating the liver to break down glycogen and release

glucose to the blood. Review Figure 51.17, ANIMATED TUTORIAL 51.2 • Food intake is governed by sensations of hunger and satiety, which are determined by brain mechanisms responding to feedback signals such as insulin, leptin, and ghrelin. Review Figure 51.18, ANIMATED TUTORIAL 51.3

CHAPTER 52 Salt and Water Balance and Nitrogen Excretion

52.1 How Do Excretory Systems Maintain Homeostasis? • Excretory systems maintain the osmolarity and volume of the extracellular fluids and eliminate the waste products of nitrogen metabolism through the processes of filtration, reabsorption, and secretion. Urine is the output of excretory systems. • There is no active transport of water, so water must be moved across membranes by a difference in either osmolarity or pressure. • Water enters and leaves cells by osmosis. To achieve cellular water balance, animals must maintain the osmolarity of their extracellular fluids within an acceptable range. • Marine animals can be osmoconformers or osmoregulators. Freshwater animals must be osmoregulators and must continually excrete water and conserve salts. Terrestrial animals are osmoregulators, but the nature of their regulation depends on environment and lifestyle. • Apart from regulating osmolarity of cells and extracellular fluids, animals must also regulate their ionic composition by conserving some ions and secreting others. Salt glands are adaptations for secretion of NaCl. Review Figure 52.2

52.2 How Do Animals Excrete Nitrogen? • Aquatic animals that breathe water can eliminate nitrogenous wastes such as ammonia by diffusion across their gill membranes. Terrestrial animals and some aquatic animals must detoxify ammonia by converting it to urea or uric acid before excretion. Review Figure 52.3 • Depending on the form in which they excrete their nitrogenous wastes, animals are classified as ammonotelic, ureotelic, or uricotelic.

52.3 How Do Invertebrate Excretory Systems Work? • The protonephridia of flatworms consist of flame cells and excretory tubules. Extracellular fluid is filtered into the tubules, which process the filtrate to produce a dilute urine. Review Figure 52.4 • In annelid worms, blood pressure causes filtration of the blood across capillary walls. The filtrate enters the coelomic cavity, where it is taken up by metanephridia, which alter the composition of the filtrate by active transport mechanisms. Review Figure 52.5, ACTIVITY 52.1 • The Malpighian tubules of insects receive ions and nitrogenous wastes by active transport across the tubule cells. Water follows by osmosis. Ions and water are reabsorbed from the rectum, so the insect excretes semisolid wastes. Review Figure 52.6

52.4 How Do Vertebrates Maintain Salt and Water Balance? • Marine bony fishes produce little urine. Chondrichthyans retain urea and TMAO, so the osmolarity of their body fluids remains close to that of seawater. • Reptiles and birds have skin with low water permeability and excrete nitrogenous wastes as uric acid in a semisolid form. • Mammals produce urine that is more concentrated than their extracellular fluids. • The nephron, the functional unit of the vertebrate kidney, consists of a glomerulus, in which blood is filtered, a renal tubule, which use processes of active secretion and reabsorption to convert the glomerular filtrate into urine to be excreted, and a system of peritubular capillaries, which surround the tubule and support its functions of secretion and reabsorption. Review Figure 52.7, ACTIVITY 52.2

52.5 How Does the Mammalian Kidney Produce Concentrated Urine? • The concentrating ability of the mammalian kidney is a function of its anatomy, which enables countercurrent exchange. Review Figure

52.9 • The glomeruli and the proximal and distal convoluted tubules are located in the cortex of the kidney. Certain molecules are actively reabsorbed from the glomerular filtrate by the tubule cells, and other molecules are actively secreted. Straight sections of renal tubules called loops of Henle and collecting ducts are arranged in parallel in the medulla of the kidney. Review ACTIVITY 52.3 • Salts, water, and valuable molecules such as glucose and amino acids are reabsorbed in the proximal convoluted tubule without the renal filtrate becoming more concentrated, although its composition changes. • The loops of Henle create a concentration gradient in the interstitial fluid of the renal medulla by a countercurrent multiplier mechanism. Urine flowing down the collecting ducts to the ureter is concentrated by the osmotic reabsorption of water caused by the concentration gradient in the surrounding interstitial fluid. Review Figure 52.10, ANIMATED TUTORIAL 52.1 • Hydrogen ions secreted by the renal tubules are buffered in the urine by bicarbonate and other chemical buffering systems. Review Figures 52.11, 52.12

52.6 How Are Kidney Functions Regulated? • Kidney function in mammals is controlled by autoregulatory mechanisms that maintain a constant high glomerular filtration rate (GFR) even if blood pressure varies. • An important autoregulatory mechanism is the release of renin by the kidney when blood pressure falls. Renin activates angiotensin, which causes the constriction of efferent glomerular arterioles and peripheral blood vessels, causes the release of aldosterone (which enhances water reabsorption), and stimulates thirst. Review Figure 52.14, ANIMATED TUTORIAL 52.2 • Changes in blood pressure and osmolarity influence the release of antidiuretic hormone (ADH), which controls the permeability of the collecting duct to water and therefore the amount of water that is reabsorbed from the urine. ADH stimulates the expression of and controls the intracellular location of aquaporins, which serve as water channels in the membranes of collecting duct cells. Review Figures 52.15, 52.16 • When the volume of blood returning to the heart increases and stretches the atrial walls, atrial natriuretic peptide (ANP) is released, which causes increased excretion of salt and water. See Activity 52.4 for a review of the major human organ systems.

CHAPTER 53 Animal Behavior

53.1 What Are the Origins of Behavioral Biology? • Ivan Pavlov's discovery of conditioned reflexes and B. F. Skinner's research on operant conditioning as a model for learning led to an approach called behaviorism that mainly carried out laboratory experiments on rats and a few other animal models. Review Figure 53.1 • Ethology focuses on both the proximate causes of behavior (the immediate cause of the behavior, and how the behavior develops) and on the ultimate causes (how the behavior affects the animal's evolutionary fitness). • A major focus of the ethologists was fixed action patterns and their releasers. They performed deprivation experiments as well as breeding experiments to demonstrate that certain behaviors are genetically determined. Review Figure 53.2.

53.2 How Do Genes Influence Behavior? • Breeding experiments can reveal whether a behavioral phenotype is inherited. Quantitative trait analysis can reveal candidate genes that influence a behavior. Gene knockout experiments can reveal the roles of specific genes underlying a behavioral phenotype. Review Figure 53.3 • Most behaviors are complex traits involving many genes that function in cascades and offer many points for a change in a single gene to influence behavior. Review Figure 53.4

53.3 How Does Behavior Develop? • Hormones can determine the pattern of behavior that develops and the timing of its expression. Review Figure 53.5 • Imprinting is a process by which an animal learns a specific set of stimuli during a limited critical or sensitive period. That critical period may be determined by hormones. • The development and expression of song in white-crowned sparrows involves a genetic predisposition to learn the species-specific song, a critical period for imprinting of a song memory, and hormonally controlled timing of song expression. Social interactions may also play a role. Review Figures 53.7, 53.8

53.4 How Does Behavior Evolve? • An animal's behavior involves a series of choices that influence its fitness. To make these choices, animals use environmental cues that are reliable predictors of the potential effects of their choice on their fitness. • The cost–benefit approach can be used to investigate the fitness value of specific behaviors. The cost of a behavior typically has three components: energetic cost, risk cost, and opportunity cost. Review Figure 53.9, ANIMATED TUTORIAL 53.1 • According to optimal foraging theory, animals should practice feeding behaviors that maximize their energetic gain at the least cost. Review Figure 53.11, ANIMATED TUTORIAL 53.2

53.5 What Physiological Mechanisms Underlie Behavior? • Circadian rhythms control the daily cycle of behavior. Without environmental time cues, circadian rhythms free-run with a period that is genetically programmed. They are normally entrained to the light–dark cycle by environmental cues. Review Figure 53.13, ANIMATED TUTORIAL 53.3 • Forms of navigation used by animals to find their way in the environment include piloting (orienting to landmarks), distance– direction navigation, and bicoordinate navigation. Navigation mechanisms include celestial navigation and a time-compensated solar compass. Review Figures 53.15–53.17, ANIMATED TUTORIALS 53.4, 53.5 • The behaviors of individuals may become communication signals if the transmission of information benefits both the sender and the receiver. Review Figure 53.18, ACTIVITY 53.1 • Chemical communication signals (pheromones) can be highly specific and have different time courses. Visual signals can convey complex messages rapidly, but only if the recipient can see the sender. Acoustic signals can travel over long distances, do not require a focused recipient, and can be modified to reveal or conceal directional information. Tactile signals can convey complex messages when animals are in close proximity.

53.6 How Does Social Behavior Evolve? • Polygynous mating systems, in which one male controls and mates with many females, can result in great variation in male reproductive success. Polyandry—a female mating with multiple males—can evolve in circumstances in which a male can make a substantial contribution to the survival of his offspring. • The fitness an individual gains by producing offspring (direct fitness) plus the fitness it gains by increasing the reproductive success of relatives with whom it shares alleles (indirect fitness) is called inclusive fitness. Kin selection may favor altruistic behavior toward relatives, despite its cost to the performer, if it increases the performer's inclusive fitness. • As a result of haplodiploidy, the sex determination mechanism of hymenopteran insects, nonreproductive female workers (sisters) share more alleles with one another than reproductive females share with their own offspring. Review Figure 53.21 • Haplodiploidy has probably facilitated the evolution of eusocial behavior in this group through kin selection. Eusociality has also arisen in diploid species in which chances of individual reproductive success are extremely low. • Group living confers benefits such as greater foraging efficiency and protection from predators, but it also has costs, such as increased competition for food and ease of transmission of diseases. See ACTIVITY 53.2 for a concept review of this chapter

PART TEN, ECOLOGY

CHAPTER 54 Ecology and the Distribution of Life

54.1 What Is Ecology? • Ecology is the scientific investigation of interactions among organisms, between organisms and their physical environment, and the patterns of distribution and abundance resulting from these interactions. • Environmentalism is the use of ecological knowledge to inform our decisions about the stewardship of natural resources. • An organism's environment encompasses both abiotic (physical and chemical) components and biotic components (other living organisms).

54.2 Why Do Climates Vary Geographically? • Weather refers to atmospheric conditions at a particular place and time. Climate is the average of atmospheric conditions, and the variation in those conditions, found in a particular place over an extended period of time. • The solar energy that reaches a given unit of Earth's surface depends primarily on the angle of the sun's radiation, which in turn is a function of latitude. The tilt of Earth's axis results in seasonal variation in temperature and day length. Review Figures 54.1, 54.2 • Latitudinal variation in solar energy input drives atmospheric circulation patterns. Review 54.3 • Global surface wind patterns are driven by atmospheric circulation and Earth's rotation; these prevailing winds in turn drive ocean surface currents. Review Figure 54.4, 54.5 • Organisms respond to climatic challenges with physiological, morphological, and behavioral adaptations.

54.3 How Is Life Distributed in Terrestrial Environments? • A biome is an environment that is shaped by its climatic and geographic attributes and characterized by ecologically similar organisms. Review Figure 54.7 • The distribution of terrestrial biomes is determined primarily by climate, but other factors, such as soil characteristics and fire, also influence vegetation. • Biomes include Arctic and alpine tundra, boreal forest, temperate evergreen and temperate deciduous forests, temperate grasslands, hot and cold deserts, chaparral, thorn forest and savanna, tropical deciduous forest, and tropical rainforest. See ANIMATED TUTORIAL 54.1, 54.2

54.4 How Is Life Distributed in Aquatic Environments? • Aquatic biomes do not depend on plants for their structure in the way terrestrial biomes do. Salinity is the primary factor that distinguishes aquatic biomes. • The marine biome is characterized by high salinity. Marine life zones are determined by distance from the surface, which influences how much light is available to sustain photosynthetic organisms, and by distance from the shore. Review Figure 54.9 • Freshwater biomes are distinguished by their water movement (standing versus flowing water). Standing water (lakes and ponds), like ocean basins, can be divided into life zones distinguished by depth and distance from shore. Review Figure 54.10 • The physical conditions in streams and rivers change along their length as water flows from the source to the mouth. • In freshwater wetlands, water levels fluctuate because of variation in water input and output. • Estuaries are bodies of water where salt and fresh water mix. This biome supports many unique species.

54.5 What Factors Determine the Boundaries of Biogeographic Regions? • Biogeography is the scientific study of the patterns of distribution of populations, species, and ecological communities. • The boundaries of the biogeographic regions are drawn where assemblages of species change dramatically over short distances. These boundaries are generally continental in scale and correspond to present or

past barriers to dispersal. Review Figures 54.11, 54.12, ACTIVITY 54.1 • Continental drift explains some discontinuous distributions that include more than one biogeographic region. Review Figure 54.13 • Biogeographers can transform phylogenetic trees into area phylogenies to understand how organisms came to occupy their present-day distributions. Review Figure 54.14 • Both vicariant events and dispersal across barriers generate discontinuous species distributions. Review Figure 54.15.

CHAPTER 55 Population Ecology

55.1 How Do Ecologists Measure Populations? • A population consists of the individuals of a species that interact with one another within a particular area at a particular time. • The density of a population is the number of individuals per unit of area or volume. • Ecologists have developed many ways of counting individuals as well as ways of estimating population sizes from a sample, such as the mark–recapture method. Review Figure 55.2 • Populations have a characteristic age structure and pattern of dispersion. Review Figures 55.3, 55.4, ANIMATED TUTORIAL 55.1

55.2 How Do Ecologists Study Population Dynamics? • Demographic events—births, deaths, immigration, and emigration—determine the size of a population. • Life tables provide summaries of demographic events in a population. A cohort life table tracks a cohort of individuals born at the same time and records the survivorship and fecundity of those individuals over time. Review Table 55.1 • Life table data can be used to construct a survivorship curve. Ecologists describe three general types of survivorship curves, which reflect different life history patterns. Review Figure 55.5 • The life history strategy of an organism describes how it partitions its time and energy among growth, maintenance, and reproduction.

55.3 How Do Environmental Conditions Affect Life Histories? • A population's per capita growth rate (r) is the difference between the per capita birth rate (b) and the per capita death rate (d). • Life history traits within a species may vary with habitat. • Interactions with other species and the abiotic environment can influence the evolution of a species' life history traits.

55.4 What Factors Limit Population Densities? • Populations can exhibit exponential growth for short periods, but eventually their resources become depleted, causing birth rates to drop and death rates to rise. Review Figure 55.7, ANIMATED TUTORIAL 55.2 • Logistic growth is the pattern seen when the growth of a population slows as its density approaches the environmental carrying capacity (K). Review Figure 55.8, ANIMATED TUTORIAL 55.3, ACTIVITY 55.1 • Species that are r-strategists have life histories that allow for high intrinsic rates of increase. K-strategists persist at or near the carrying capacity (K) of their environment. Many species' life history strategies fall along a continuum between these two extremes. Review Figure 55.9 • Population densities are determined by both density-dependent and density-independent factors. Several factors—including resource abundance, body size, and social organization—influence population densities.

55.5 How Does Habitat Variation Affect Population Dynamics? • No species is found everywhere within its range. Members of most species live in distinct habitat patches. • A metapopulation consists of separate subpopulations among which some individuals move on a regular basis. Review Figure 55.11 • Extinction of a subpopulation may be prevented by immigration of individuals from another

subpopulation, a process known as the rescue effect. Corridors between patches may facilitate such movement. Review Figure 55.12, ANIMATED TUTORIAL 55.4

55.6 How Can We Use Ecological Principles to Manage Populations? • To manage populations, it is important to understand their life histories and population dynamics. To maximize the number of individuals that can be harvested from a population, the population should be kept well below carrying capacity. • Reducing the carrying capacity of the environment for a pest species is a more effective way to reduce its population than killing its members. • Earth's carrying capacity for humans depends on our use of resources and the effects of our activities on the environment. Human populations grow at different rates in different parts of the world. Review Figures 55.16, 55.17

CHAPTER 56 Species Interactions and Coevolution

56.1 What Types of Interactions Do Ecologists Study? • Species interactions can be grouped into categories. Antagonistic interactions include predation, herbivory, and parasitism, all of which benefit a consumer while harming the species that is consumed. Mutualism benefits both participants, whereas competition harms both. Commensalism benefits one participant with no effect on the other; amensalism has no effect on one participant but harms the other. Review Figure 56.1, ACTIVITY 56.1 • The evolution of an adaptation in one species may lead to the evolution of an adaptation in a species with which it interacts, a process known as coevolution. A series of reciprocal adaptations among consumers and their resource species can lead to a coevolutionary arms race. See ANIMATED TUTORIAL 56.1

56.2 How Do Antagonistic Interactions Evolve? • Predators kill the individuals they consume (their prey). Over its lifetime, a predator kills and consumes many prey individuals. • Some prey species avoid detection by means such as crypsis. Others defend themselves by physical or chemical means. Chemically defended animals often advertise their toxicity with aposematism, or warning coloration. Review Figure 56.4, 56.5 • In Batesian mimicry, a nontoxic species mimics a toxic species. In Müllerian mimicry, two or more toxic species converge to resemble one another. Review Figure 56.6 • Herbivores generally consume only parts of their food plants and usually do not kill them. • Many herbivores have evolved resistance to the defensive secondary metabolites produced by plants, and some have incorporated them into their own defenses against predators. • Parasites consume certain tissues in one or a few host individuals of another species without necessarily killing them. Microparasites include viruses, bacteria, and protists; large numbers of these organisms can live and reproduce within the body of the host and are often pathogenic. Macroparasites are less intimately associated with their hosts but can nonetheless affect host fitness.

56.3 How Do Mutualistic Interactions Evolve? • Mutualistic interactions involve an exchange of benefits. Many mutualisms arise in environments where resources are in short supply. • Reciprocal adaptations are most likely to arise when an increase in dependency on a partner provides an increase in the benefits realized from the interaction. • Some animals "farm" fungal species, which provide them with food. Other mutualisms involve an exchange of food or housing for defense. Review Figures 56.9, 56.10, ANIMATED TUTORIAL 56.2

• Many mutualisms between plants and animals involve an exchange of food for transport. In plant–pollinator interactions, animals that collect and transport pollen are rewarded with pollen or nectar. • Broad suites of floral characteristics that are attractive to certain types of pollinators exemplify diffuse coevolution. Some plant–pollinator mutualisms, however, are much more specific and exclusive. Review Figure 56.11, Table 56.1 • Plants that depend on frugivores for seed dispersal must balance the need to discourage frugivores from eating fruits before the seeds are mature, attract frugivores when the seeds are mature, and protect the seeds from destruction in a frugivore's digestive tract.

56.4 What Are the Outcomes of Competition? • Competition occurs whenever a resource is not sufficient to meet the needs of all organisms with an interest in that resource. • Competition may result in local extinction of the inferior competitor, an outcome called competitive exclusion. Alternatively, selection pressures resulting from competition may change the ways in which the competing species use a limiting resource, an outcome called resource partitioning. Interference competition occurs when an individual interferes with a competitor's access to a limiting resource. Exploitation competition occurs when a limiting resource is available to all competitors and the outcome of competition depends on the relative efficiency with which competitors use the resource. • Exploitation competition may lead to character displacement, in which attributes of a species vary depending on whether a competitor is present or absent. Review Figure 56.14 • Species may compete indirectly even when they are not present in the same place at the same time, as, for example, when they share a common predator. • A species' niche is the set of physical and biological conditions it requires to persist. Although a species may be able to persist under a wide range of resource conditions (its fundamental niche), competitors may restrict its use of resources in a particular location (its realized niche). Review Figure 56.15

CHAPTER 57 Community Ecology

57.1 What Are Ecological Communities? • A community is a group of species that coexist and interact within a defined area. • Gross primary productivity (GPP) is the rate at which the primary producers in a community turn solar energy into chemical energy via photosynthesis. Net primary production represents the energy incorporated into primary producer biomass. Review Figure 57.2, ACTIVITY 57.1 • A food web is a diagram of the feeding relationships in a community. Review Figure 57.3 • The organisms in a community can be divided into trophic levels based on the energy sources they use. Primary producers get their energy from sunlight; primary consumers get their energy by eating primary producers; secondary consumers get their energy by eating primary consumers; and so on. Review Table 57.1, ACTIVITY 57.2 • Organisms that consume the dead bodies of other organisms or their waste products are called detritivores or decomposers. Omnivores are organisms that feed at multiple trophic levels. • Ecological efficiency is the overall transfer of energy from one trophic level to the next. Pyramid diagrams illustrate the proportions of energy or biomass that flow to each successive trophic level. Review Figure 57.4 • Species diversity tends to increase with productivity up to a point; however; if productivity increases beyond that point, species diversity may decline. Review Figure 57.5

57.2 How Do Interactions among Species Influence Communities? • The interactions of a consumer with other species can result in a trophic cascade: a series of indirect effects across successive trophic levels. Review Figure 57.6 • Organisms that build structures that create habitat for other species are known as ecosystem engineers. • Keystone species have an influence on their community that is disproportionate to their abundance. Review Figure 57.7

57.3 What Patterns of Species Diversity Have Ecologists Observed? • Species diversity encompasses species evenness as well as species richness. Review Figure 57.8 • Species diversity can be measured at multiple spatial scales: within a single community or habitat, or over a range of communities in a geographic region. • Latitudinal gradients in diversity, with the greatest diversity at low latitudes, have been observed in many taxa. Review Figure 57.9 • According to the theory of island biogeography, the equilibrium number of species on an island represents a balance between the rate at which species immigrate to the island from the mainland species pool and the rate at which resident species go extinct. Review Figure 57.11, ANIMATED TUTORIAL 57.1

57.4 How Do Disturbances Affect Ecological Communities? • A disturbance is a disruption in a community caused by a discrete external force, often abiotic in nature. • Succession is a predictable pattern of change in community composition following a disturbance. In directional succession, species come and go in a predictable sequence until a climax community forms and persists for an extended time. • Primary succession begins on sites that lack living organisms. Secondary succession begins on sites where some organisms have survived a disturbance. Review Figures 57.13, 57.14, ANIMATED TUTORIAL 57.2 • In any pattern of succession, species that become established may facilitate or inhibit colonization by other species. • In cyclical succession, the climax community is maintained by periodic disturbances. • Heterotrophic succession in detritus-based communities does not rely on photosynthesis and therefore differs in a number of ways from other types of succession.

57.5 How Does Species Richness Influence Community Stability? • Species-rich communities use resources more efficiently, and thus tend to vary less in productivity, than do less diverse communities. Review Figure 57.16 • Monocultures are subject to pest outbreaks, whereas agricultural communities containing greater species diversity tend to be more stable.

CHAPTER 58 Ecosystems and Global Ecology

58.1 How Does Energy Flow through the Global Ecosystem? • An ecosystem includes all of the organisms in an ecological community as well as the physical and chemical factors that influence those organisms. • Energy flows and chemical elements cycle through ecosystems. Review Figure 58.1 • Terrestrial net primary production varies across the globe, reflecting differences in solar energy input and the climate patterns that result from them. Review Figures 58.2, 58.3 • Productivity in aquatic ecosystems is limited by light, temperature, and nutrient availability. Review Figure 58.4 • Humans appropriate about one-quarter of Earth's average annual net primary production, although this amount varies regionally.

58.2 How Do Materials Move through the Global Ecosystem? • Chemical elements cycle through biotic and abiotic compartments of the global ecosystem. Review Figure 58.5 • The movement of elements through the biotic compartment of ecosystems, from uptake by autotrophs to decomposition, generally occurs on a local scale. • Most global air circulation takes place in the lowest layer of the atmosphere, the troposphere. An ozone layer in the stratosphere absorbs ultraviolet radiation. Review Figure 58.6 • Carbon dioxide, water vapor, and other greenhouse gases in the atmosphere are transparent to sunlight but trap heat, thus warming Earth's surface. Review Figure 58.7, ANIMATED TUTORIAL 58.1 • Because the geological processes that move elements on land are so slow (on the scale of millions of years), there are large regional and local variations in the supply of particular elements within the terrestrial

compartments. • Some nutrients enter fresh waters from the atmosphere in rainfall, but most are released from rocks by weathering. They are usually carried rapidly to lakes or to the oceans. • Turnover occurs regularly in temperate-zone lakes in both spring and fall, bringing nutrients to the surface and oxygen to the deeper waters. Review Figure 58.8 • Most materials that cycle through biotic and abiotic compartments end up in the oceans, where they eventually sink to the bottom. • Fires release the chemical elements from the vegetation they burn. Those vaporized elements enter the atmosphere, where they can be carried into groundwater by rain.

58.3 How Do Specific Nutrients Cycle through the Global Ecosystem? • The pattern of movement of a chemical element through the biotic and abiotic compartments of the global ecosystem is its biogeochemical cycle. • The hydrologic cycle is driven by the sun, which evaporates more water from the ocean surface than it returns by precipitation. The excess precipitation that falls on land eventually returns to the oceans, primarily in rivers. Review Figure 58.9, ANIMATED TUTORIAL 58.2 • Groundwater plays a minor role in the hydrologic cycle, but underground aquifers are being seriously depleted by human activities. • Carbon is removed from the atmosphere by photosynthesis and returned to the atmosphere by metabolism and burning. Review Figure 58.10, ANIMATED TUTORIAL 58.3 • The concentration of CO_2 in the atmosphere has increased greatly in the last 150 years, largely because of the burning of fossil fuels. This buildup of CO_2 is warming the global climate. Review Figures 58.11–58.13 • As a result of agricultural use of fertilizers and the burning of fossil fuels, total nitrogen fixation by humans is nearly equal to natural nitrogen fixation. Review Figures 58.14. 58.15, ANIMATED TUTORIAL 58.4 • Human alteration of the nitrogen cycle has resulted in excesses of nitrogen compounds in bodies of water, leading to eutrophication and dead zones. • The burning of fossil fuels releases sulfur and nitrogen into the atmosphere, leading to acid precipitation. Review Figure 58.16 • Agricultural use of fertilizers and clearing of land have dramatically increased the input of phosphorus into soils and fresh waters. Review Figure 58.17

58.4 What Goods and Services Do Ecosystems Provide? • The goods and services provided by ecosystems include food, clean water, flood control, pollination, pest control, climate regulation, spiritual fulfillment, and aesthetic enjoyment. Most ecosystem services either are irreplaceable or the technology necessary to replace them is prohibitively expensive. • Efforts to enhance the capacity of an ecosystem to provide some goods and services often come at the cost of the system's ability to provide others.

58.5 How Can Ecosystems Be Sustainably Managed? • The total economic value of an ecosystem managed in a sustainable manner often is higher than that of a converted or intensively exploited ecosystem. Review Figure 58.19 • Recognition of the value of ecosystem goods and services that are now perceived as "public goods" may induce government action to protect them. Public education is needed to make people aware of how much they benefit from ecosystem goods and services. See ACTIVITY 58.1 for a concept review of this chapter

CHAPTER 59 Biodiversity and Conservation Biology

59.1 What Is Conservation Biology? • Conservation biology is an applied scientific discipline devoted to protecting and managing biodiversity. • Conservation biologists recognize that an understanding of the evolutionary processes that generate biodiversity is essential to protecting it. They also understand that

ecosystems are dynamic, and that humans are part of those ecosystems. • Species extinctions have always occurred, but they are currently occurring at a rate that rivals those of the five great mass extinctions in Earth's history. • There are many compelling reasons for protecting biodiversity, including the maintenance of the species and ecosystems that provide humans with goods and services.

59.2 How Do Conservation Biologists Predict Changes in Biodiversity? • Although our understanding of biodiversity is incomplete, biologists have identified many species that are threatened with extinction and have developed a classification system designed to aid in establishing policies for their protection. See Figure 59.3 • Biologists use the species–area relationship and the theory of island biogeography to estimate rates of extinction likely to be caused by habitat loss. • To estimate a species' risk of extinction, statistical models take into account data on population sizes, demographic traits, genetic variation, physiology, and behavior. • Rarity is not always a cause for concern, but species whose populations are shrinking rapidly are usually at risk of extinction.

59.3 What Human Activities Threaten Species Persistence? • Habitat loss is the most important cause of species endangerment worldwide. As habitats become increasingly fragmented, more species are lost from those habitats. Small habitat patches can support only small populations and are adversely influenced by edge effects. Review Figures 59.4, 59.5, 59.6, ANIMATED TUTORIAL 59.1 • Overexploitation has historically been the most important cause of species extinctions, and it is still a major threat to biodiversity today. • Some species introduced to regions outside their original range become invasive, causing extinctions of native species that have not evolved defenses against these new antagonists and competitors. • Climate change is likely to become an increasingly important cause of extinctions for those species that cannot shift their ranges as rapidly as the climate warms. Review Figure 59.9

59.4 What Strategies Are Used to Protect Biodiversity? • Establishing protected areas is crucial to conserving biodiversity. Protected areas are selected by taking into account species richness, endemism, and imminence of threats. Review Figures 59.10, 59.11 • Restoration ecology is an important conservation strategy because many degraded ecosystems will recover very slowly, if at all, without human assistance. Review Figure 59.14 • International trade in endangered species is controlled by regulations that most countries endorse. • Conservation biologists work to determine which species are likely to become invasive and prevent their introduction to new areas. Review Figure 59.16 • Recognition of the economic value of biodiversity can help justify conservation efforts. Review Figure 59.18 • Even within landscapes where people live and extract resources, steps may be taken to protect biodiversity. This approach is known as reconciliation ecology. • Captive breeding programs can maintain some endangered species for the short term while threats to their persistence in other natural habitats are reduced or removed. See ACTIVITY 59.1 for a concept review of this chapter

BONUS: REGARDING THE TEN PARTS

1) PART ONE, THE SCIENCE OF LIFE AND ITS CHEMICAL BASIS Chapter 1 introduces the core concepts set forth in the "Vision and Change" report and continues the much-praised approach of focusing on a specific series of experiments that introduces students to biology as an experimentally based and

constantly expanding science. Chapter 1 emphasizes the principles of biology that are the foundation for the rest of the book, including the unity of life at the cellular level and how evolution unites the living world. Chapters 2–4 cover the chemical principles and building blocks that underlie life. Chapter 4 also includes a discussion of how life could have evolved from inanimate chemicals.

2) PART TWO, CELLS The nature of cells and their role as the structural and functional basis of life is foundational to biology. These revised chapters include expanded explanations of how experimental manipulations of living systems have been used to discover cause and effect in biology. Students who are intrigued by the question "Where did the first cells come from?" will appreciate the updated discussion of ideas on the origin of cells and organelles, as well as expanded discussion of the evolution of multicellularity and cell interactions. In response to reviewer comments, the discussion of membrane potential has been moved to Chapter 45, where students may find it to be more relevant.

3) PART THREE, CELLS AND ENERGY The biochemistry of life and energy transformations are among the most challenging topics for many students. We have worked to clarify such concepts as enzyme inhibition, allosteric enzymes, and the integration of biochemical systems. Revised presentations of glycolysis and the citric acid cycle now focus, in both text and figures, on key concepts and attempt to limit excessive detail. There are also revised discussions of the ecological roles of alternate pathways of photosynthetic carbon fixation, as well as the roles of accessory pigments and reaction center in photosynthesis.

4) PART FOUR, GENES AND HEREDITY This crucial section of the book is revised to improve clarity, link related concepts, and provide updates from recent research results. Rather than being segregated into separate chapters, material on prokaryotic genetics and molecular medicine are now interwoven into relevant chapters. Chapter 11 on the cell cycle includes a new discussion of how the mechanisms of cell division are altered in cancer cells. Chapter 12 on transmission genetics now includes coverage of this phenomenon in prokaryotes. Chapters 13 and 14 cover gene expression and gene regulation, including new discoveries about the roles of RNA and an expanded discussion of epigenetics. Chapter 15 covers the subject of gene mutations and describes updated applications of medical genetics.

5) PART FIVE, GENOMES This extensive and up-to-date coverage of genomes expands and reinforces the concepts covered in Part Four. The first chapter of Part Five describes how genomes XII Preface are analyzed and what they tell us about the biology of prokaryotes and eukaryotes, including humans. Methods of DNA sequencing and genome analysis, familiar to many students in a general way, are rapidly improving, and we discuss these advances as well as how bioinformatics is used. This leads to a chapter describing how our knowledge of molecular biology and genetics underpins biotechnology—the application of this knowledge to practical problems and issues such as stem cell research. Part Five closes with a unique sequence of two chapters that explore the interface of developmental processes with molecular biology (Chapter 19) and with evolution (Chapter 20), providing students with a link between these two crucial topics and a bridge to Part Six.

6) PART SIX, THE PATTERNS AND PROCESSES OF EVOLUTION Many students come to the introductory biology course with ideas about evolution already firmly in place. One common view, that evolution is only about Darwin, is firmly put to rest at the start of Chapter 21, which not only illustrates the practical value of fully understanding modern evolutionary biology, but briefly and succinctly traces the history of "Darwin's dangerous idea" through the twentieth century and up to the present syntheses of molecular evolutionary genetics and evolutionary developmental biology—fields of study that uphold and support

the principles of evolutionary biology as the basis for comparing and comprehending all other aspects of biology. The remaining sections of Chapter 21 describe the mechanisms of evolution in clear, matter-of-fact terms. Chapter 22 describes phylogenetic trees as a tool not only of classification but also of evolutionary inquiry. The remaining chapters cover speciation and molecular evolution, concluding with an overview of the evolutionary history of life on Earth.

7) PART SEVEN, THE EVOLUTION OF DIVERSITY Continuing the theme of how evolution has shaped our world, Part Seven introduces the latest views on biodiversity and the evolutionary relationships among organisms. The chapters have been revised with the aim of making it easier for students to appreciate the major evolutionary changes that have taken place within the different groups of organisms. These chapters emphasize understanding the big picture of organismal diversity—the tree of life—as opposed to memorizing a taxonomic hierarchy and names. Throughout the book, the tree of life is emphasized as a way of understanding and organizing biological information.

8) PART EIGHT, FLOWERING PLANTS: FORM AND FUNCTION The emphasis of this modern approach to plant form and function is not only on the basic findings that led to the elucidation of mechanisms for plant growth and reproduction, but also on the use of genetics of model organisms. In response to users of earlier editions, material covering recent discoveries in plant molecular biology and signaling has been reorganized and streamlined to make it more accessible to students. There are also expanded and clearer explanations of such topics as water relations, the plant body plan, and gamete formation and double fertilization.

9) PART NINE, ANIMALS: FORM AND FUNCTION This overview of animal physiology begins with a sequence of chapters covering the systems of information—endocrine, immune, and neural. Learning about these information systems provides important groundwork and explains the processes of control and regulation that affect and integrate the individual physiological systems covered in the remaining chapters of the Part. Chapter 45, “Neurons and Nervous Systems,” has been rearranged and contains descriptions of exciting new discoveries about glial cells and their role in the vertebrate nervous system. The organization of several other chapters has been revised to reflect recent findings and to allow the student to more readily identify the most important concepts to be mastered.

10) PART TEN, ECOLOGY Part Ten continues Life’s commitment to presenting the experimental and quantitative aspects of biology, with increased emphasis on how ecologists design and conduct experiments. New exercises provide opportunities for students to see how ecological data are acquired in the laboratory and in the field, how these data are analyzed, and how the results are applied to answer questions. There is also an expanded discussion of aquatic biomes and a more synthetic explanation of how aquatic, terrestrial, and atmospheric components integrate to influence the distribution and abundance of life on Earth. In addition there is an expanded emphasis on examples of successful strategies proposed by ecologists to mitigate human impacts on the environment; rather than an inventory of ways human activity adversely affects natural systems, this revised Tenth Edition provides more examples of ways that ecological principles can be applied to increase the sustainability of these systems